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COMPUTER-BASED SIMULATION AND ANALYSIS OF M116A3 AND M116A2E2 CHASSIS TRAILERS TRANSPORTING FIRE FINDER RADAR UNIT

NOVEMBER 1991

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This report presents a comparison of the ride dynamics and performance of the M116A3 and M116A2E2 chassis trailers transporting the AN/TPQ-36 Firefinder radar unit. The M116A2E2 trailer has a set of seven leaf springs and uses the M101/M116 hydraulic shock absorbers. The M116A3 trailer has a set of 11 leaf springs and uses the M103 hydraulic shock absorbers. The comparison of the performance of the two trailers is drawn from a computer-based simulation of each trailer and its prime mover using Dynamic Analysis and Design System (DADS) software. The report details the simulation of the High-Mobility Multi-Purpose Wheeled Vehicle (HMMWV) as the prime mover towing the subject trailers and payload over bumps, potholes, slaloms, side slopes, and cross-country terrain at a variety of speeds. Time history responses of important dynamic characteristics are analyzed and plotted for each simulation performed. Conclusions and recommendations are given for the use of either trailer for the transport of the Firefinder radar unit or similar high center-of-gravity payloads.

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SUMMARY

This paper describes the computer-based modeling, simulation, and analysis of the M116A3 and M116A2E2 chassis trailers. The simulations were performed by the Analytical and Physical Simulation Branch of the US Army Tank-Automotive Command, System Simulation and Technology Division. The purpose of the simulations was to determine if the M116A2E2 and/or M116A3 chassis trailers would be capable of sustaining the mission requirements as transporter of the AN/TPQ-36 Firefinder radar unit and also to determine which of the two trailers would be best for this mission.

Computer-based dynamic models of both trailers were developed using Dynamic Analysis and Design System (DADS) software and all computations were performed on the Cray 2 supercomputer located at TACOM. A series of simulations were run of each trailer with the High Mobility Multi-Purpose Wheeled Vehicle (HMMWV) as the prime mover. The Firefinder radar unit was selected as the trailer payload. The HMMWV/trailer combinations were simulated negotiating bump, pothole, slalom, and side slope courses at successively increasing speeds. Time history responses of several dynamic parameters were recorded and plotted. The primary areas of interest analyzed and compared were the roll, pitch, and yaw stability of the two trailers while performing the above mentioned simulations.

The results of the simulations indicated that the M166A2 and M116A3 would likely sustain the mission of transporting the Firefinder radar unit from a stability and ride dynamics standpoint. The modified suspension of the M116A3 trailer led to a much improved performance in ride stability over the M116A2E2 while negotiating severe vertical obstacles such as bumps and potholes. The results were most likely due to the fact that the modified suspension of the M116A3 contains a set of leaf springs with a lower spring rate and greater allowable spring travel than those of the M116A2E2, and also a set of heavier-duty, M103, gas shock absorbers. The "softer" springs and increased spring travel of the M116A3 suspension reduces the frequency of jounce stop impacts when encountering vertical obstacles. The drawback to the "softer" springs is a reduction in roll stability when performing sudden lateral movements. The differences in the two trailers was not significant in this area because the M103 shock absorbers effectively damped out the roll motion of the M116A3, thereby negating the adverse effect of the softer suspension.

INTRODUCTION/OBJECTIVE

In an effort to improve the mobility of the M116A2E2 trailer, the suspension was modified with a new set of 11 leaf springs and heavier-duty shock absorbers. The resulting trailer configuration was classified as the M116A3. The purpose of the suspension modifications was to increase the allowable spring travel distance and thereby reduce the frequency of jounce stop impacts with the trailer frame. The suspension modifications have led to the increased mobility and durability of the M116A3 trailer, and also allow for transport of payloads in excess of three quarters of a ton. Both trailers utilize HMMWV wheels and the offset axle developed by the Turtle Mountain Manufacturing Co. Table 1. lists the differences in the M116-series trailers.

M116A2	8740054
M116A2E1	Improved Springs (7 vs. 5 Leaves) Improved Frame (4" vs. 3")
M116A2E2	Offset axle Increased Track Width to 72 " HMMWV Wheels and Tires
M116A3	Improved Springs (11 Leaves) Reinforced Frame Adjustable Wheeled Landing Leg Two Rear Landing Legs M103 Shock Absorber

Table 1. M116-Series Trailers

The Analytical and Physical Simulation Branch of the U.S. Army Tank-Automotive Command, System Simulation and Technology Division (AMSTA-RYA) was asked by Product Manager Trailers (AMCPM-T) to determine if the M116A2E2/A3 trailers would meet the mission requirements of the Firefinder radar unit and to analyze the performance of the two trailers to determine which would be most suitable. As a result, the System Simulation and Technology Division developed computer-based dynamic models of the HMMWV pulling both the M116A2E2 and M116A3 trailers supporting the Firefinder radar unit as the payload.

Each HMMWV/trailer combination was simulated negotiating a bump, pothole side slope, slalom, and Aberdeen Proving Ground course number 11 (APG 11) at a range of speeds. The purpose of the bump and pothole course simulations was to fully exercise the suspensions of the M116A2E2 and M116A3 trailers. This meant producing maximum leaf spring travel and forcing jounce stop impact between the trailer axle and frame. The effort here was to determine how much improvement in ride stability was witnessed in the M116A3 due to the increased spring travel allowance and lower spring rate of the 11 leaf springs, compared to the M116A2E2 with the original suspension. The main drawback to the increased spring travel allowance of the M116A3 is an increase in overall center of gravity height. Also, the reduced spring rate of the 11 leaf springs, 680 lb/in, compared to the 720 lb/in rate of the six leaf springs used on the M116A2E2 results in a loss of longitudinal roll stability when encountering sudden lateral movements. For this reason, the HMMWV/trailer combinations were simulated negotiating a 120-foot longitudinal by 11-foot lateral transition slalom maneuver, and a 20 percent right and left side slope roll course. The purpose of these simulations was to determine how much the change in leaf springs deteriorated the roll stability of the M116A3 as compared to the M116A2E2. The trailers were also simulated traversing the APG 11 cross-country course. The APG 11 course has a root mean square (RMS) vertical amplitude value of 1.37 inches which can be considered as hilly cross-country. The purpose of these simulations was to determine the overall stability of the two trailer configurations traveling over a high amplitude, high frequency road profile. A variety of each trailer's dynamic parameters were recorded, plotted, analyzed, and compared for every simulation.

PROCEDURE

The computer-based models were developed using the DADS software package developed by Computer Aided Design Software Inc.(CADSi). The leaf springs and shock absorbers were modeled using translational-spring-damping actuator (TSDA) elements which incorporate the respective spring rates and damping characteristics. The trailer chassis, axle, payload, and wheels were modeled as independent bodies. The mass and inertia properties of each body along with the longitudinal, lateral, and vertical stiffness properties of the tires were also included in the models. Several massless links , or distance constraints, that do not appear in the actual trailers, were incorporated in the model. These massless links limit the trailer axle motion to vertical translation and roll about the longitudinal axis relative to the trailer frame and also account for the roll center and roll stiffness properties of the trailers. A computer-based DADS model of the HMMWV, created for a previous simulation project, was used as the prime mover for the trailers.

The HMMWV/trailer models were simulated negotiating a 12 inch bump, with 20 percent approach/departure angles, at speeds ranging from 15-25 mph (all simulation speeds were in increments of 5 mph; i.e. 10, 15, 20 mph, etc.). The models also were simulated negotiating both 9- and 12-inch potholes, with 100 percent approach/departure angles, at speeds ranging from 5-15 mph. For both the bump and pothole courses, the HMMWV/trailer combination was simulated traveling on flat, paved road for 20 feet, encountering the obstacle with the driver's side wheels of the HMMWV and trailers, and then traveling on flat, paved road until a steady state response was again reached for each dynamic parameter recorded. The HMMWV/trailer combinations were simulated negotiating a slalom course which consisted of starting in the right lane of a flat, paved road and maneuvering into the left lane around a pylon 120 feet forward of the starting position and returning to the right lane within another 120-foot transition. These slalom maneuvers were performed at 20-30 mph. The next set of simulations consisted of the HMMWV/trailer combinations traversing a side slope course. The side slope course requires the combination to travel 20 feet of flat, paved road, 100 feet of transition to a 20 percent right side slope, 100 feet of 20% right side slope, 100 feet of transition to a 20 percent left side slope, 100 feet of 20 percent left side slope, and finally transition back to flat paved road. The roll course simulations were performed at vehicle speeds of 20-30 mph. The APG 11 course simulations were run at speeds of 15-25 mph. These speeds were chosen to be five mph above and below the Firefinder mission requirement of 20 mph maximum speed for this type of cross country course. Table 2. summarizes the simulations performed.

COURSE	DESCRIPTION	SPEEDS
BUMP	12" HEIGHT, 20% APP/DEP ANGLE	15,20,25 MPH
POTHOLE	9" DEPTH, 100% APP/DEP ANGLE	5,10,15 MPH
POTHOLE	12" DEPTH, 100% APP/DEP ANGLE	5,10,15 MPH
SLALOM	120' x 11' LONGITUDINAL/LATERAL	20,25,30 MPH
SIDE SLOPE	20% RIGHT & LEFT SIDE SLOPE	20,25,30 MPH
APG 11	400 FT. X-COUNTRY, RMS 1.37	15,20,25 MPH

Table 2. Computer Simulations Performed

For every simulation, the driver's side leaf spring's deflection and force was recorded, along with the roll, pitch, and yaw angles of the subject trailers. The time history responses of these dynamic parameters were plotted against each other for each trailer for comparison purposes. In all, 30 simulations were run (15 per trailer) and a total of 240 time history dynamic parameter responses were recorded.

RESULTS AND DISCUSSION

The results of the computer-based simulation of the HMMWV/M116A2E2 and HMMWV/M116A3 combinations are presented and discussed for each type (course/maneuver) of simulation performed. The primary dynamic parameters of interest analyzed are the roll, pitch, and yaw angles of the M116A2E2 and the M116A3 trailers while transporting the Firefinder radar unit.

Bump Course (15-25 mph); (See App. A, plots 1-9.)

The bump course maneuver showed the most significant difference in the performance of the trailers. The M116A3 was able to negotiate the 12-inch bump and remain upright for all speeds simulated. The M116A2E2, on the other hand, showed a roll over situation at the 20 and 25 mph speeds. The reason for this difference is the increased allowable spring travel and reduced spring stiffness of the M116A3 allowed that trailer's suspension to absorb most of the impact of the obstacle whereas the M116A2E2 was forced into a much more severe jounce stop impact. This resulted in a much greater roll moment to be imparted to the M116A2E2, thereby resulting in the roll over. It should be emphasized that encountering a 12-inch bump at speeds up to 25 mph would be an unlikely occurrence during the Firefinder mission. This type of situation would probably only occur rarely during an evasive maneuver or panic situation.

Pothole Course (5-15 mph); (See App. B, plots 1-18.)

The result of the pothole simulations, for both the 9- and 12-inch holes, show that the roll angle of the M116A3 is much less severe than that of the M116A2E2. This difference becomes greater at the higher speeds. At 15 mph, the roll angle of the M116A3 is as much as 50 percent less than that of the M116A2E2 for both pothole depths. This shows much greater stability in the M116A3 compared to the M116A2E2 although neither trailer came close to a rollover situation. The reasons for the improved roll stability are the same as for the improved performance of the M116A3 during the bump course simulations, reduced spring stiffness and increased allowable spring travel. The pitch and yaw angles of each trailer remained insignificant throughout all of the pothole course simulations.

Slalom Maneuver (20-30 mph); (See App. C, plots 1-9.)

There were no significant differences in the roll, pitch, and yaw angles throughout the slalom maneuver simulations. Both trailer configurations remained stable.

Side Slope Course (20-30 mph); (See App. D, plots 1-9.)

There were no significant differences in the roll, pitch, and yaw angles throughout the side slope course simulations. Both trailer configurations remained stable.

APG 11 Cross-Country Course (15-25 mph); (See App. E, plots 1-9)

The APG 11 cross-country course simulations showed the most drastic differences between the two trailers in the area of roll stability. The M116A3 again out performed the M116A2E2 in this area. The 25 mph simulation showed as much as an 80 percent reduction in the roll angle of the M116A3 compared to the M116A2E2. Although neither trailer reached a rollover situation, the M116A2E2 appeared much less stable. Again, the improved suspension of the M116A3 is most likely accountable for this difference.

Another area of concern in the transport of the Firefinder radar unit is the high center of gravity of the trailer and payload configuration. In the case of these two trailers, it has been determined that the increased spring travel of the M116A3 will not significantly affect the overall trailer vertical cg height because the reduced spring rate of the leaf springs allows the trailer to settle at a center of gravity height only slightly greater than that of the M116A2E2. Table 3. shows the relative difference in cg height of the two trailers with the fire finder radar unit as payload.

	Spring Rate	Jounce Clearance (unloaded)	Jounce Clearance (w/firefinder)
M116A2E2	720 #/in	4.485 in	2.93 in
M116A3	680 #/in	5.25 in	3.60 in
CG Height Increase		0.765 in	0.67 in

Table 3. Modified Suspension Effect on Trailer Center of Gravity Height.

One final note, the M103 gas shock absorbers used on the M116A3 showed a considerable improvement over the shocks on the M116A2E2. All plots indicate the M116A3 damped out considerably quicker than the M116A2E2. This is an important factor in overall system stability since this most likely accounts for there being no significant differences in the overall trailer roll stability in the slalom and side slope courses.

CONCLUSIONS/RECOMMENDATIONS

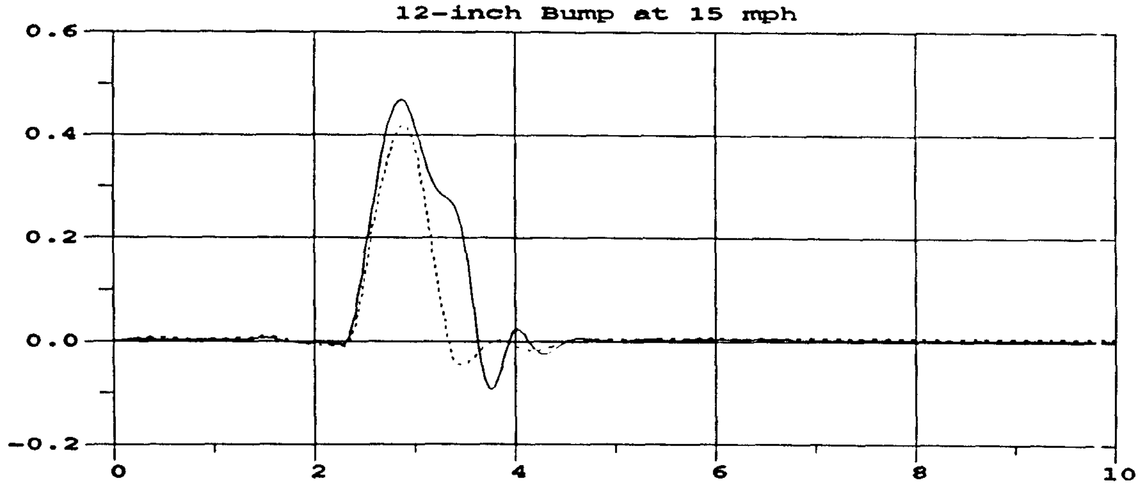
Based on the results of the computer-based simulation, ride dynamics, and stability analysis of the M116A3 and M116A2E2 trailer/Firefinder configurations, both trailers would likely be able to perform the mission of transporting the Firefinder radar unit, however, the M116A3 would be the better of the two.

The simulations show an improvement in the performance of the M116A3 over the M116A2E2 when negotiating severe obstacles such as bumps and potholes. The difference between the two trailers in this area becomes more dramatic as the vehicle speed and/or severity of the obstacle is increased. The reason for this improvement is the increased allowable spring travel and reduced spring rate of the 11 leaf springs used on the M116A3. The increased allowable spring travel and reduced spring rate was expected to lead to a decrease in the longitudinal roll-stability of the M116A3 during sudden lateral maneuvers such as a lane change or slalom (obstacle avoidance). The reduced roll stability is caused by a reduced roll stiffness due to the "softer" 11 leaf springs on the M116A3 compared to the 6 leaf springs on the M116A2E2. The longitudinal roll stability of the M116A3, however, was not significantly different than that of the M116A2E2 during the lateral maneuvers. The use of the gas shock absorbers from the M103 trailer on the M116A3 greatly improved the damping characteristics of the M116A3 and were most likely the reason the roll stability of the two trailers was not significantly different.

APPENDIX A

Time History Plots of Bump Course Simulations

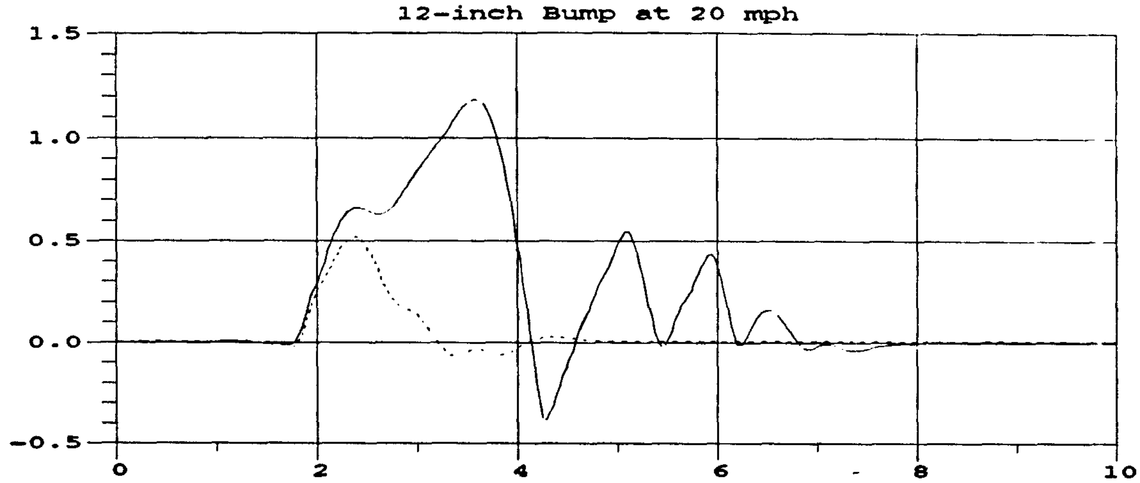
12-inch Bump at 15 mph



———— M116A2E2 ROLL ANGLE (radians) vs TIME (seconds)
------ M116A3 ROLL ANGLE (radians) vs TIME (seconds)

1

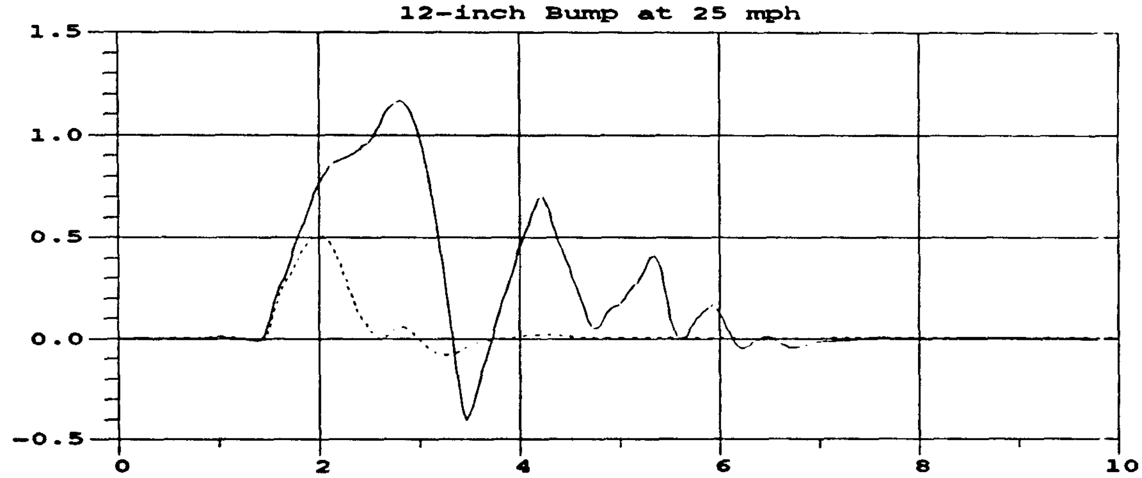
12-inch Bump at 20 mph



———— M116A2E2 ROLL ANGLE (radians) vs TIME (seconds)
------ M116A3 ROLL ANGLE (radians) vs TIME (seconds)

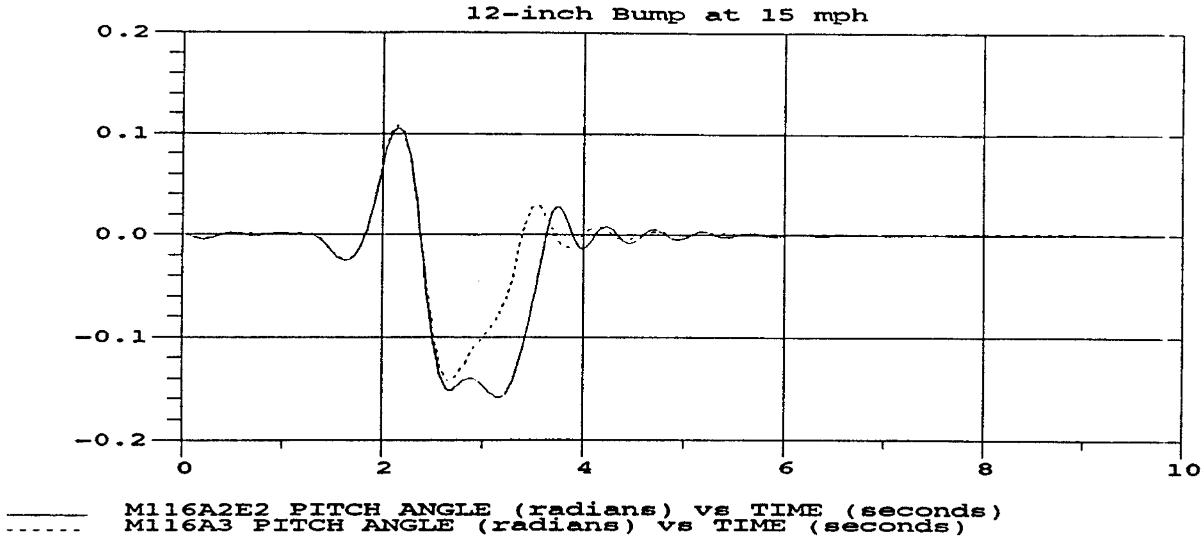
2

12-inch Bump at 25 mph

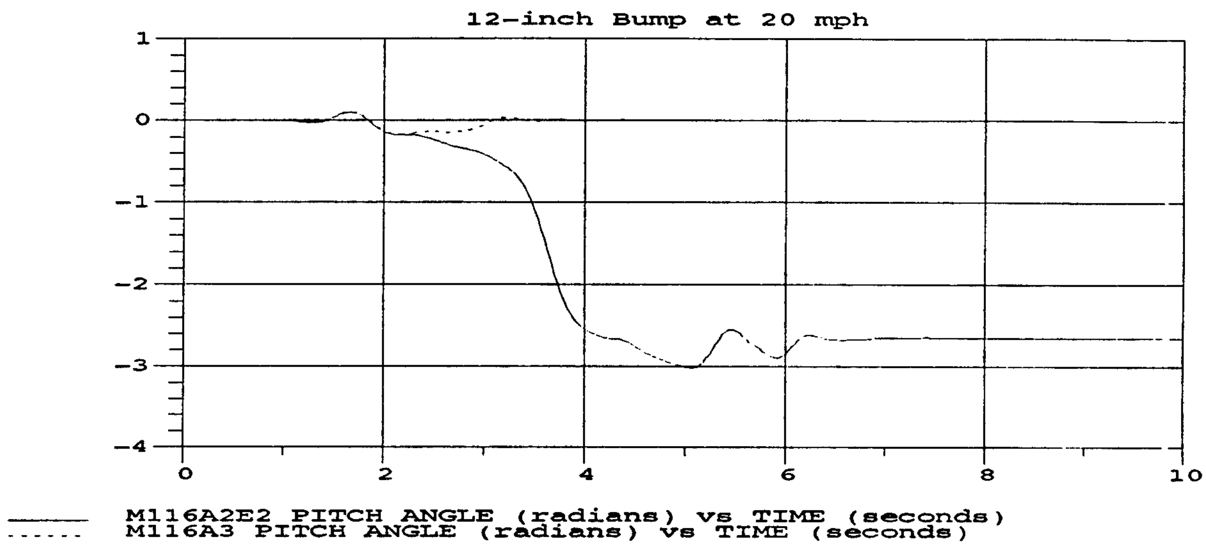


———— M116A2E2 ROLL ANGLE (radians) vs TIME (seconds)
------ M116A3 ROLL ANGLE (radians) vs TIME (seconds)

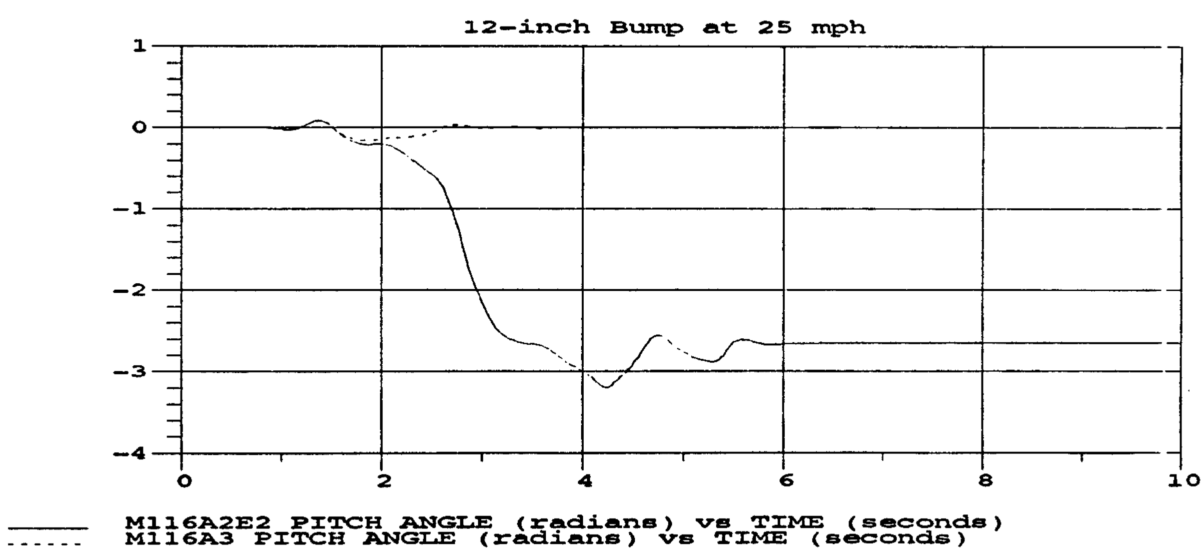
3


12-inch Bump at 15 mph
0.2
0.1
0.0
-0.1
-0.2
0
2
4
6
8
10
M116A2E2 PITCH ANGLE (radians) vs TIME (seconds)
M116A3 PITCH ANGLE (radians) vs TIME (seconds)

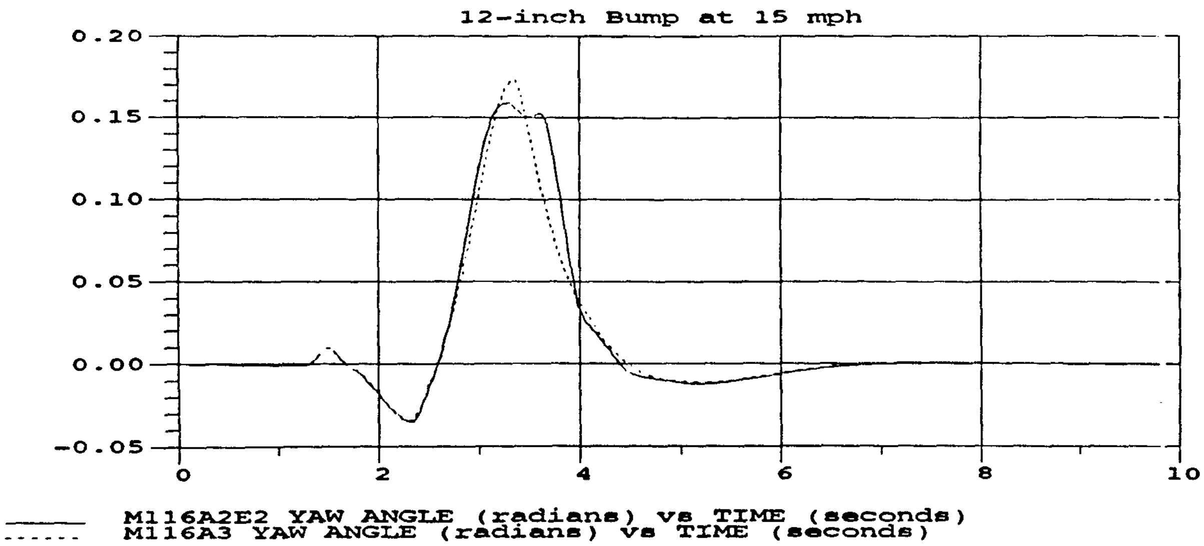
4


12-inch Bump at 20 mph
1
0
-1
-2
-3
-4
0
2
4
6
8
10
M116A2E2 PITCH ANGLE (radians) vs TIME (seconds)
M116A3 PITCH ANGLE (radians) vs TIME (seconds)

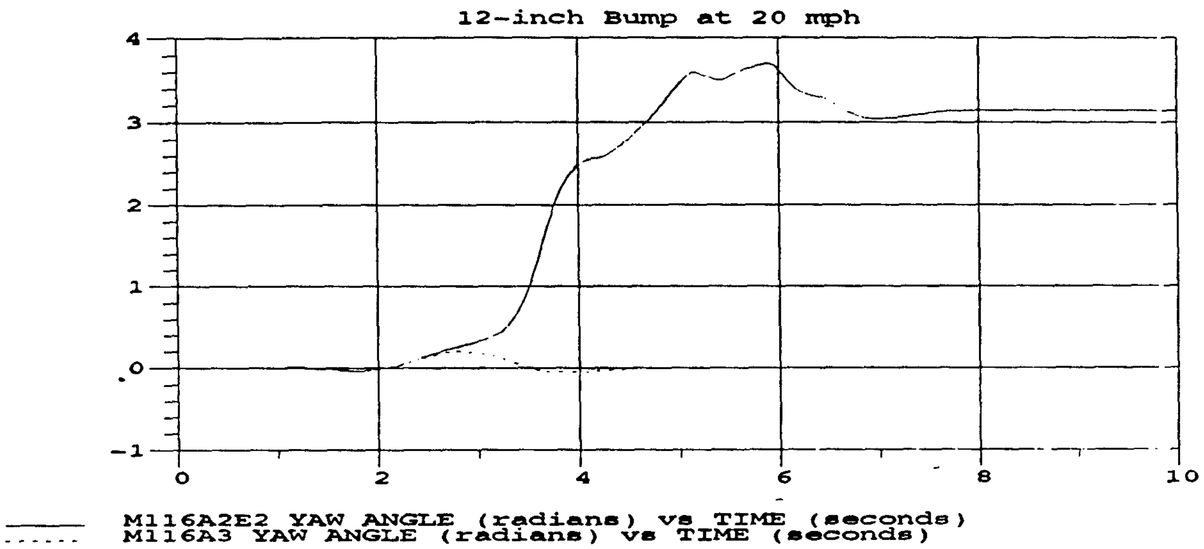
5


12-inch Bump at 25 mph
1
0
-1
-2
-3
-4
0
2
4
6
8
10
M116A2E2 PITCH ANGLE (radians) vs TIME (seconds)
M116A3 PITCH ANGLE (radians) vs TIME (seconds)

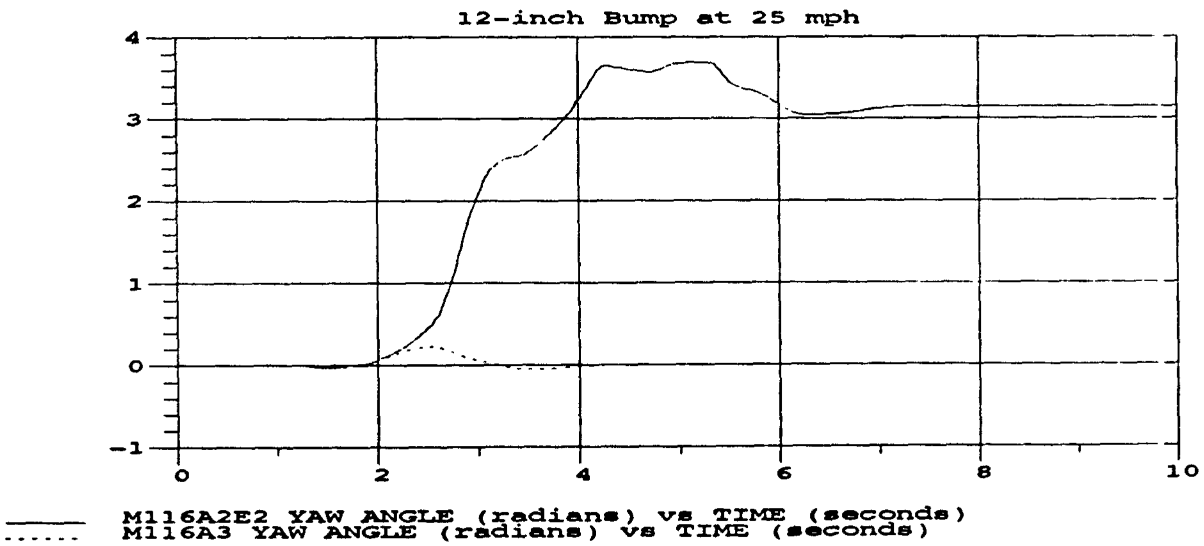
6


12-inch Bump at 15 mph
0.20
0.15
0.10
0.05
0.00
-0.05
0
2
4
6
8
10
M116A2E2 YAW ANGLE (radians) vs TIME (seconds)
M116A3 YAW ANGLE (radians) vs TIME (seconds)

7


12-inch Bump at 20 mph
4
3
2
1
0
-1
0
2
4
6
8
10
M116A2E2 YAW ANGLE (radians) vs TIME (seconds)
M116A3 YAW ANGLE (radians) vs TIME (seconds)

8

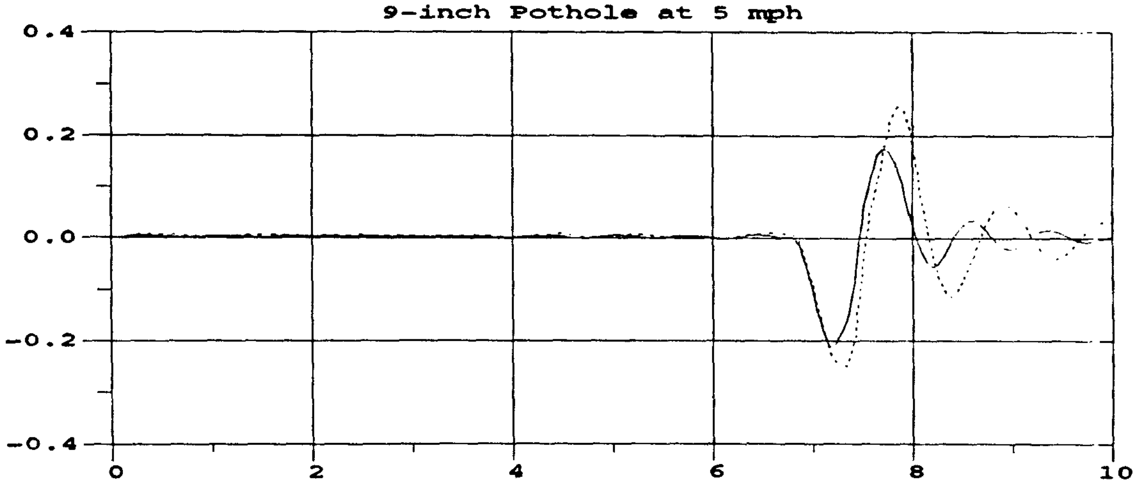

12-inch Bump at 25 mph
4
3
2
1
0
-1
0
2
4
6
8
10
M116A2E2 YAW ANGLE (radians) vs TIME (seconds)
M116A3 YAW ANGLE (radians) vs TIME (seconds)

9

APPENDIX B

Time History Plots of Pothole Course Simulations

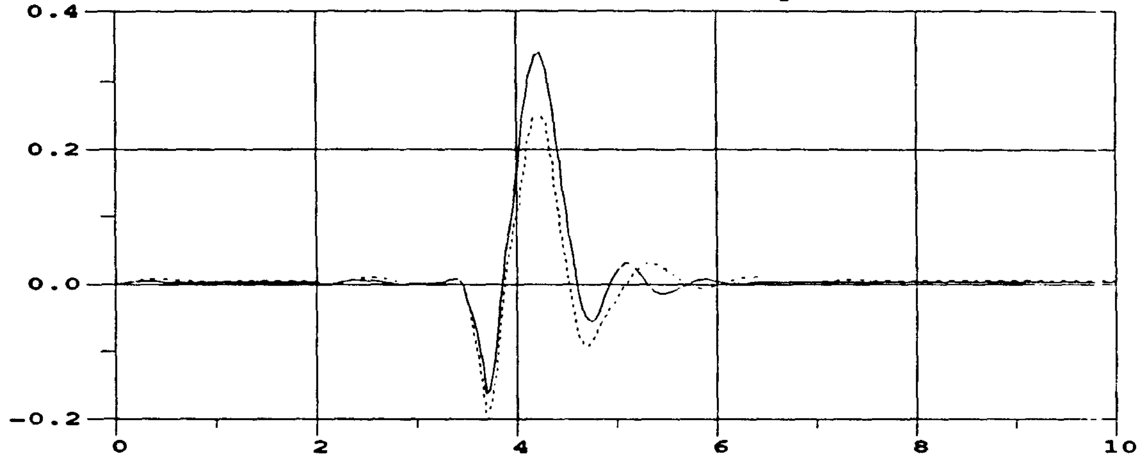
9-inch Pothole at 5 mph



M116A2E2 ROLL ANGLE (radians) vs TIME (seconds)
M116A3 ROLL ANGLE (radians) vs TIME (seconds)

1

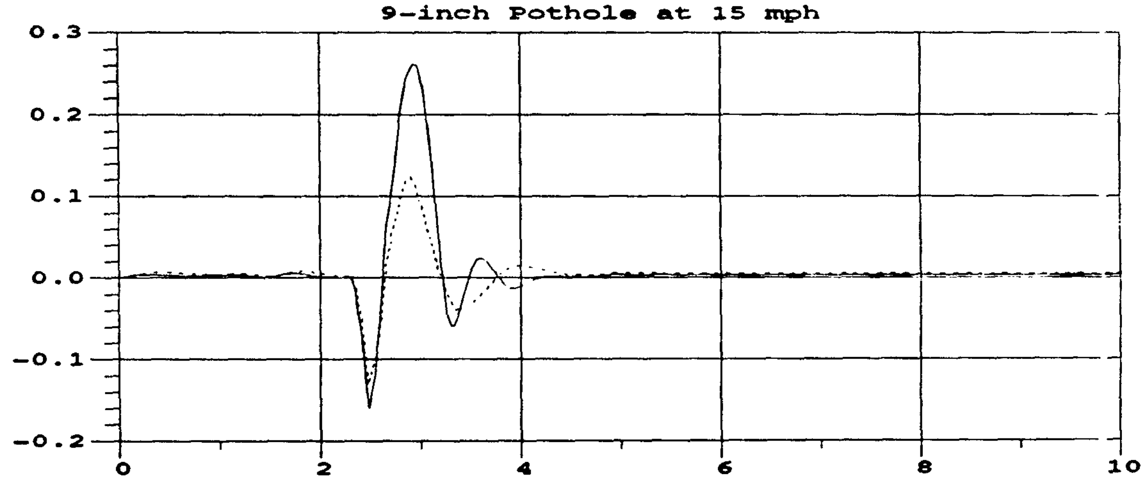
9-inch Pothole at 10 mph



M116A2E2 ROLL ANGLE (radians) vs TIME (seconds)
M116A3 ROLL ANGLE (radians) vs TIME (seconds)

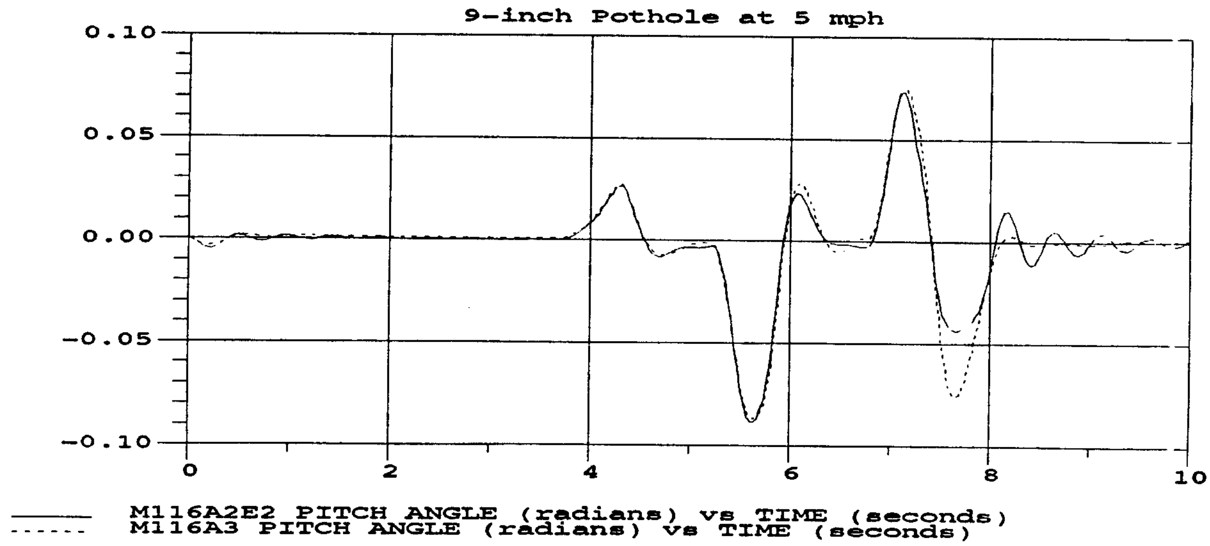
2

9-inch Pothole at 15 mph



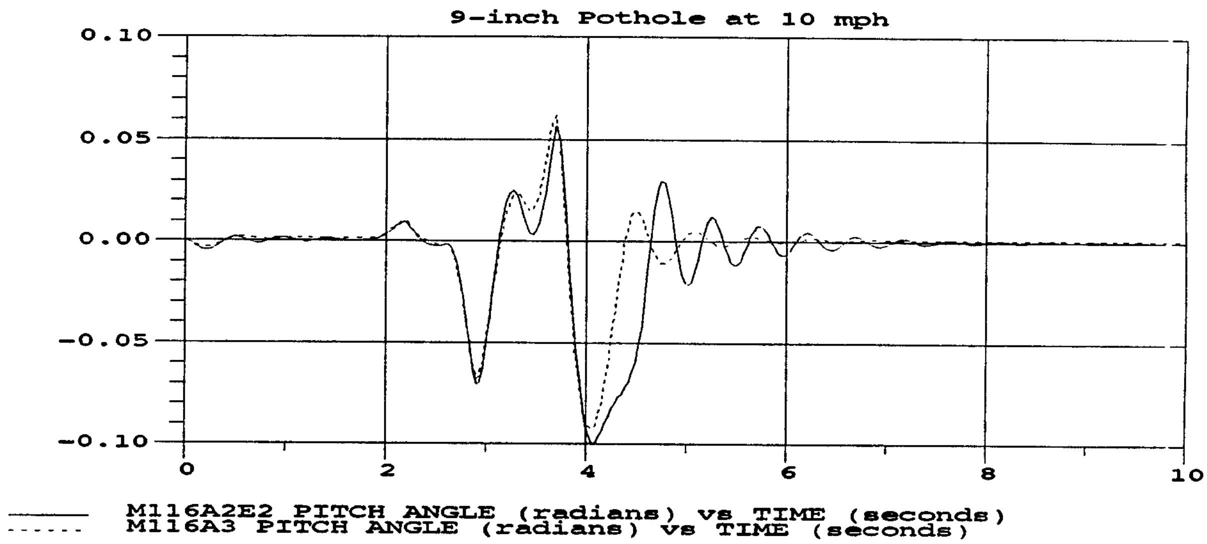
M116A2E2 ROLL ANGLE (radians) vs TIME (seconds)
M116A3 ROLL ANGLE (radians) vs TIME (seconds)

3



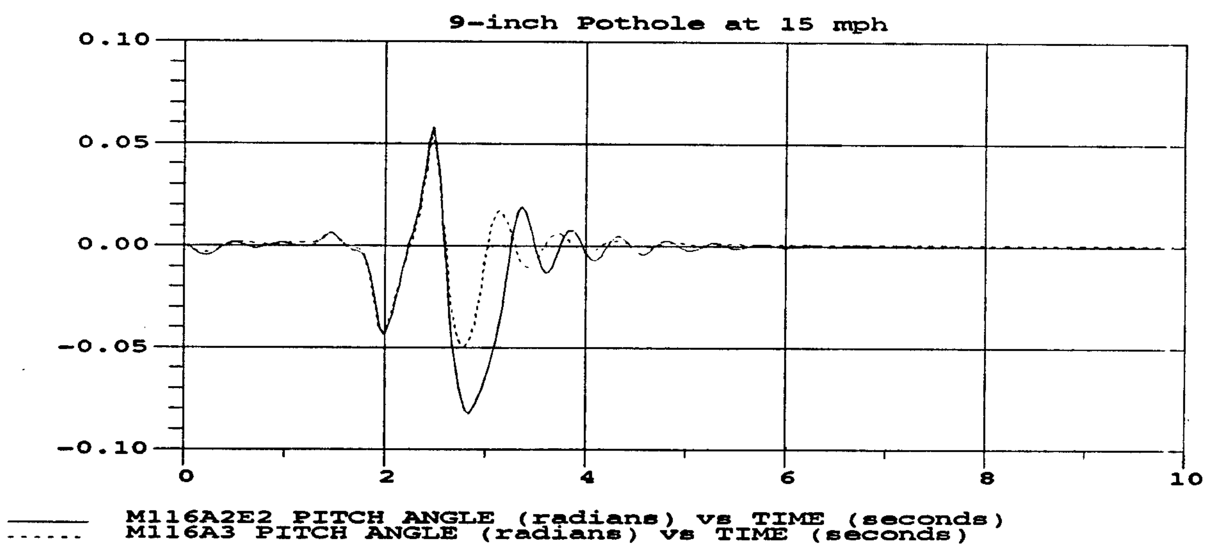
9-inch Pothole at 5 mph
0.10
0.05
0.00
-0.05
-0.10
0
2
4
6
8
10
M116A2E2 PITCH ANGLE (radians) vs TIME (seconds)
M116A3 PITCH ANGLE (radians) vs TIME (seconds)

4



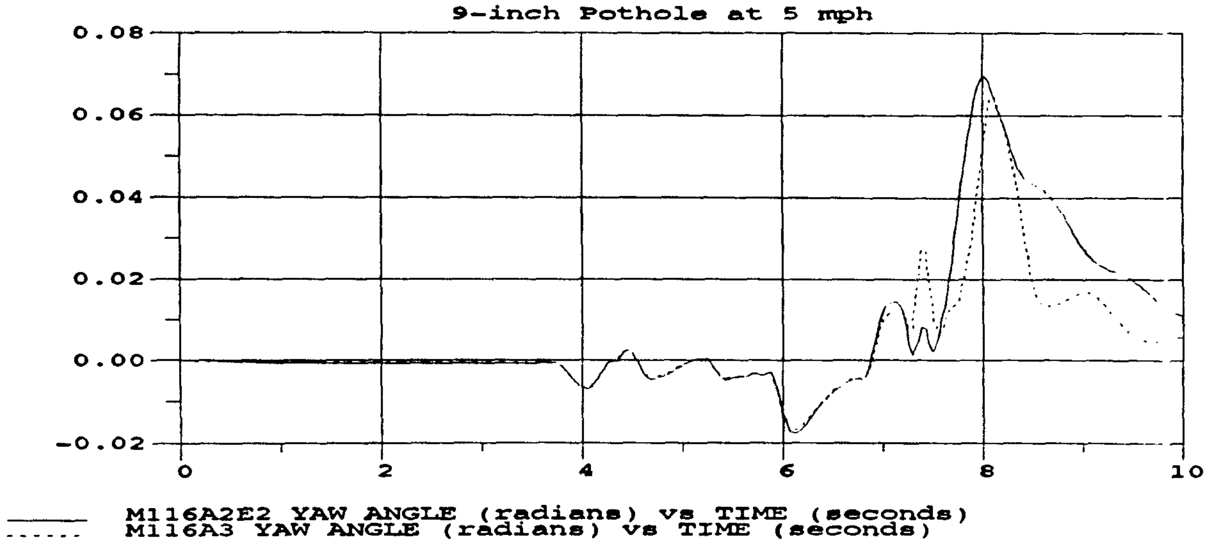
9-inch Pothole at 10 mph
0.10
0.05
0.00
-0.05
-0.10
0
2
4
6
8
10
M116A2E2 PITCH ANGLE (radians) vs TIME (seconds)
M116A3 PITCH ANGLE (radians) vs TIME (seconds)

5



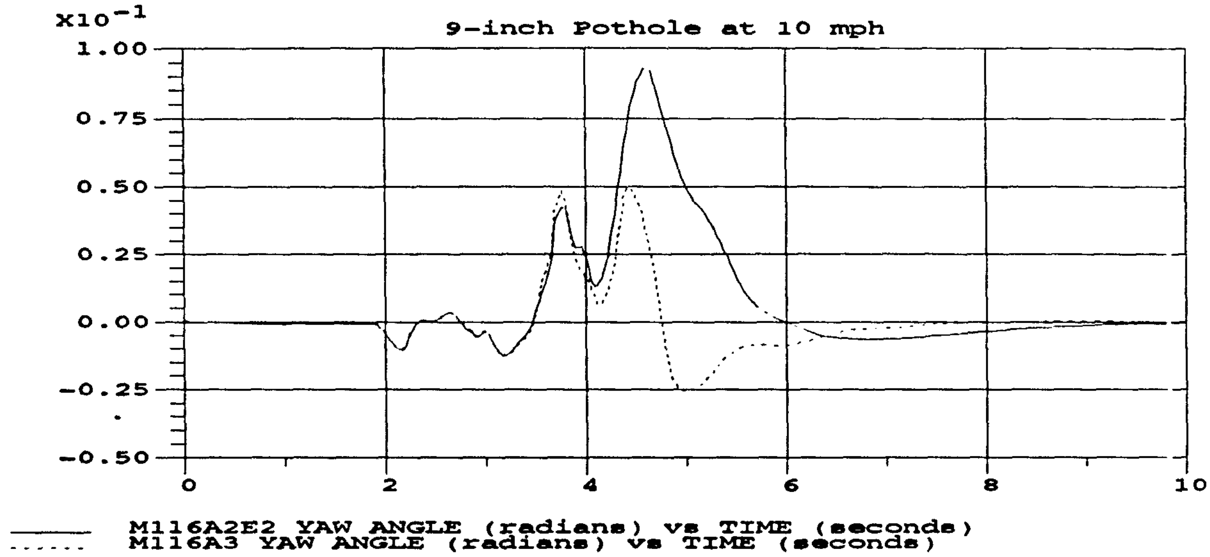
9-inch Pothole at 15 mph
0.10
0.05
0.00
-0.05
-0.10
0
2
4
6
8
10
M116A2E2 PITCH ANGLE (radians) vs TIME (seconds)
M116A3 PITCH ANGLE (radians) vs TIME (seconds)

6



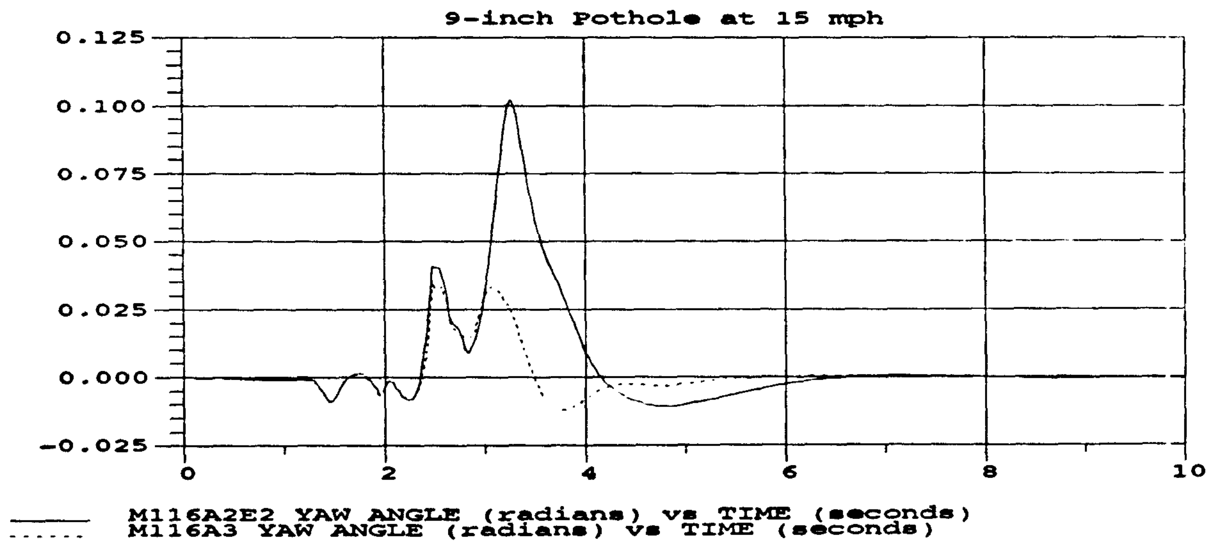
9-inch Pothole at 5 mph
0.08
0.06
0.04
0.02
0.00
-0.02
0
2
4
6
8
10
M116A2E2 YAW ANGLE (radians) vs TIME (seconds)
M116A3 YAW ANGLE (radians) vs TIME (seconds)

7



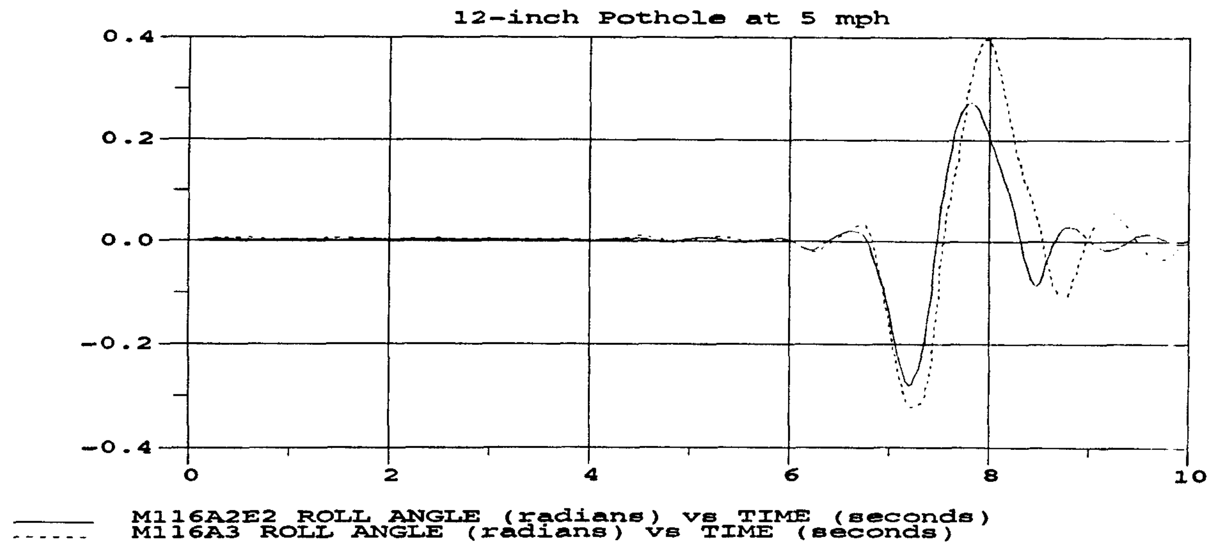
x10^-1
9-inch Pothole at 10 mph
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
0
2
4
6
8
10
M116A2E2 YAW ANGLE (radians) vs TIME (seconds)
M116A3 YAW ANGLE (radians) vs TIME (seconds)

8

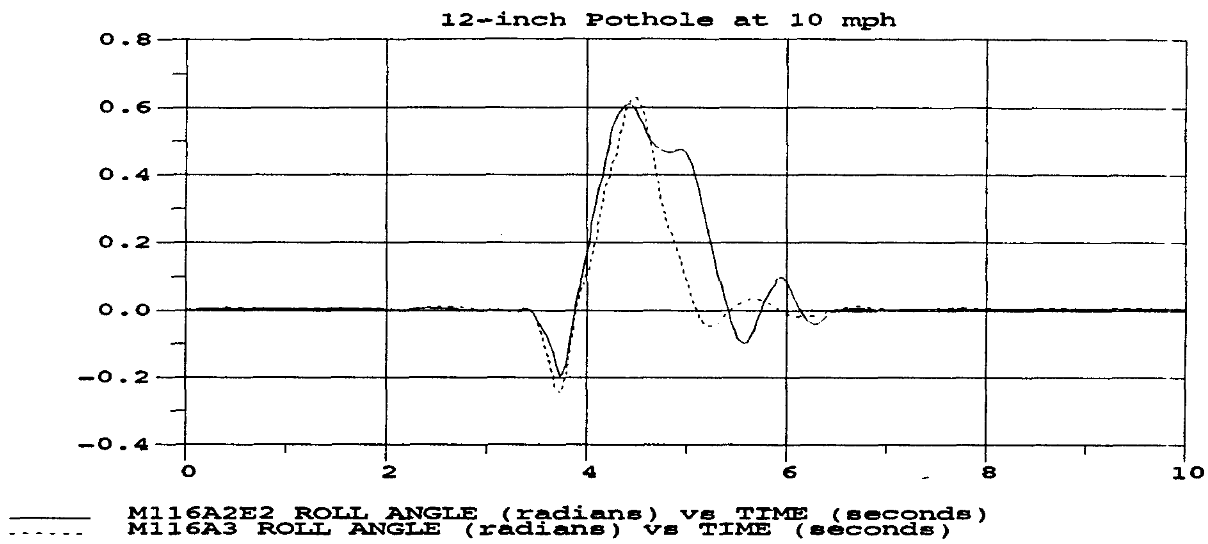


9-inch Pothole at 15 mph
0.125
0.100
0.075
0.050
0.025
0.000
-0.025
0
2
4
6
8
10
M116A2E2 YAW ANGLE (radians) vs TIME (seconds)
M116A3 YAW ANGLE (radians) vs TIME (seconds)

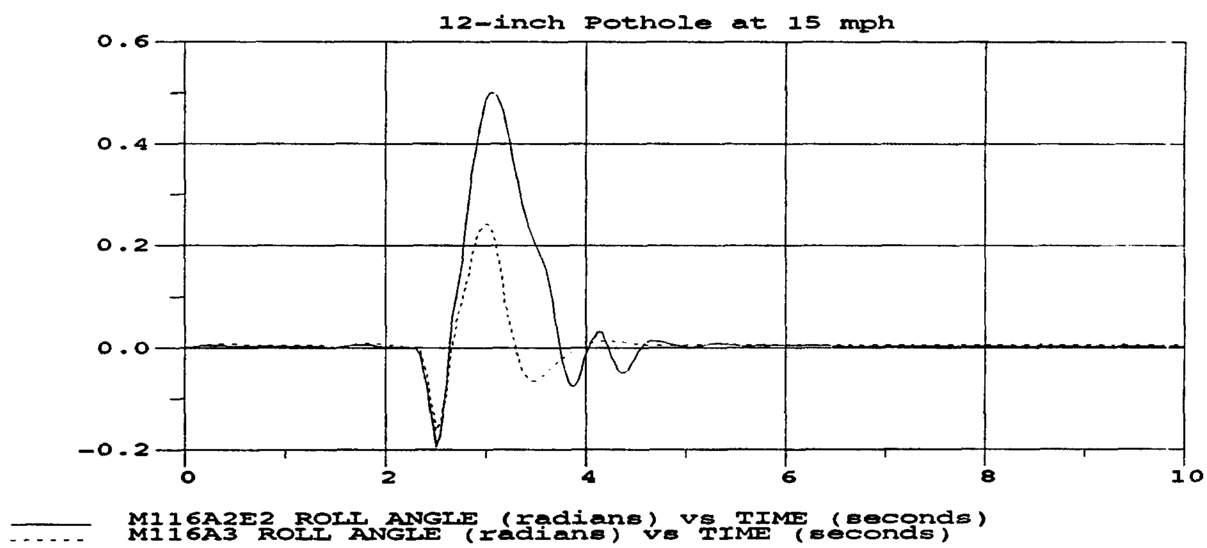
9


12-inch Pothole at 5 mph
0.4
0.2
0.0
-0.2
-0.4
0
2
4
6
8
10
M116A2E2 ROLL ANGLE (radians) vs TIME (seconds)
M116A3 ROLL ANGLE (radians) vs TIME (seconds)

10

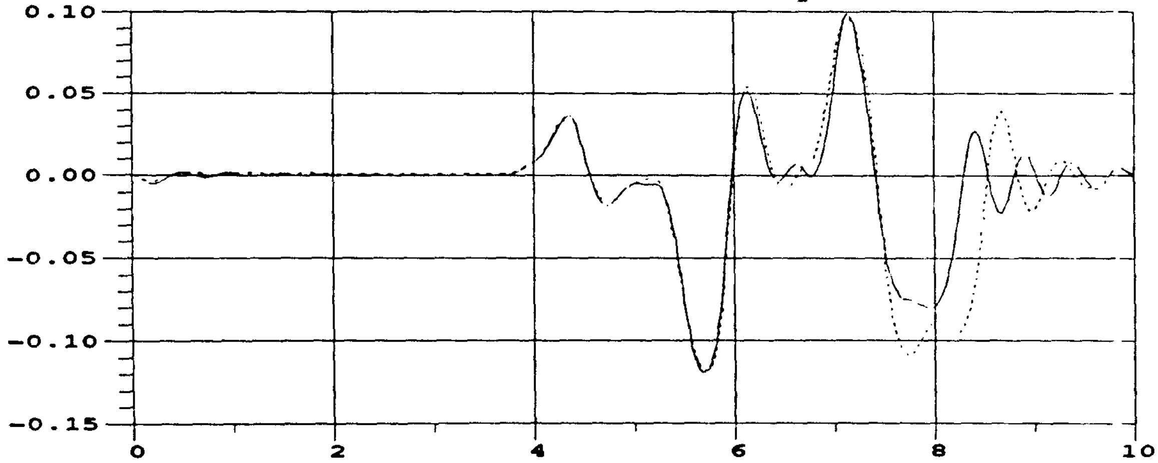

12-inch Pothole at 10 mph
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
2
4
6
8
10
M116A2E2 ROLL ANGLE (radians) vs TIME (seconds)
M116A3 ROLL ANGLE (radians) vs TIME (seconds)

11


12-inch Pothole at 15 mph
0.6
0.4
0.2
0.0
-0.2
0
2
4
6
8
10
M116A2E2 ROLL ANGLE (radians) vs TIME (seconds)
M116A3 ROLL ANGLE (radians) vs TIME (seconds)

12

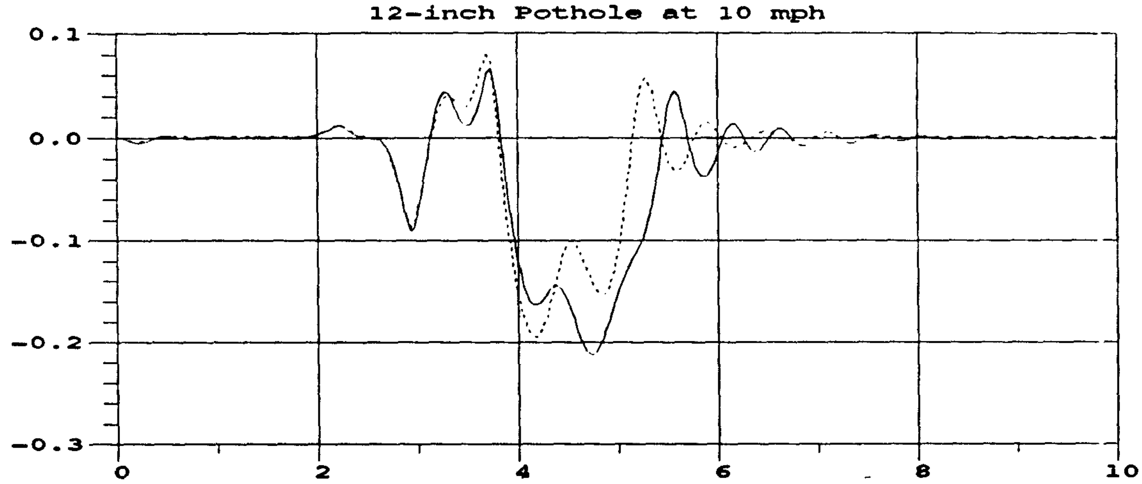
12-inch Pothole at 5 mph



M116A2E2 PITCH ANGLE (radians) vs TIME (seconds)
M116A3 PITCH ANGLE (radians) vs TIME (seconds)

13

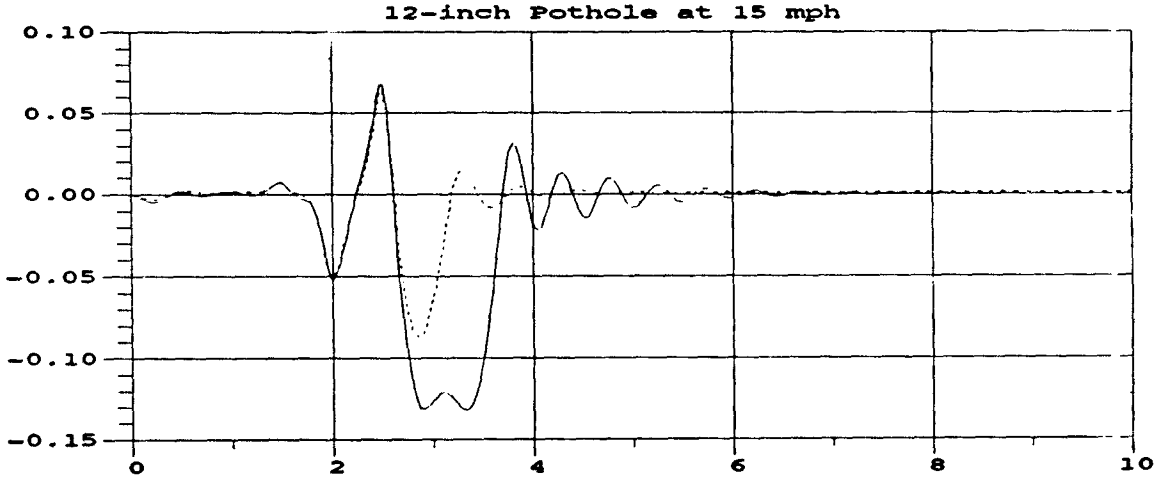
12-inch Pothole at 10 mph



M116A2E2 PITCH ANGLE (radians) vs TIME (seconds)
M116A3 PITCH ANGLE (radians) vs TIME (seconds)

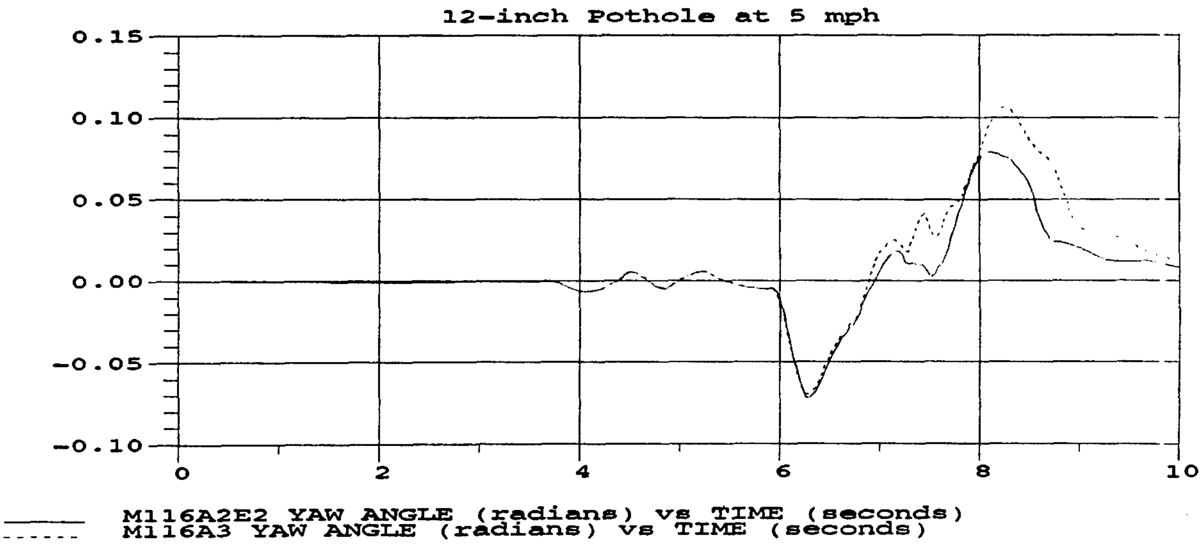
14

12-inch Pothole at 15 mph

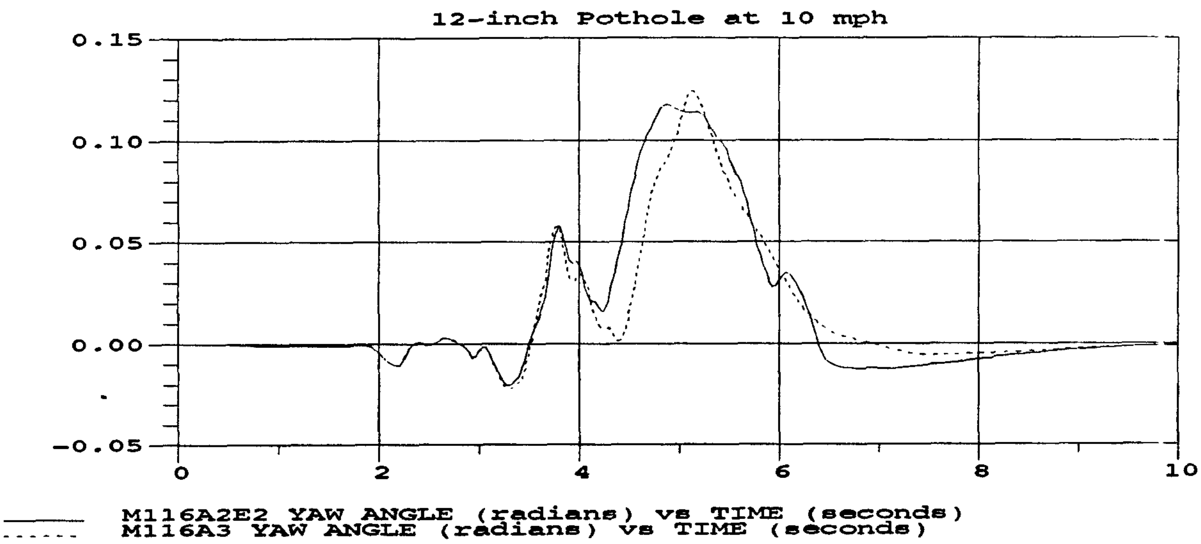


M116A2E2 PITCH ANGLE (radians) vs TIME (seconds)
M116A3 PITCH ANGLE (radians) vs TIME (seconds)

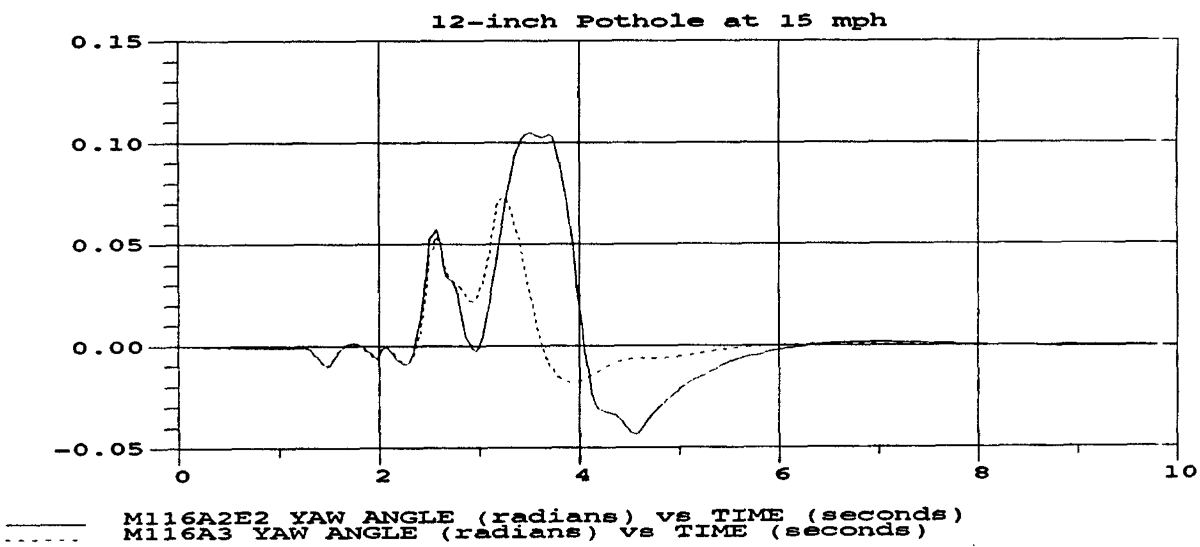
15


12-inch Pothole at 5 mph
0.15
0.10
0.05
0.00
-0.05
-0.10
0
2
4
6
8
10
M116A2E2 YAW ANGLE (radians) vs TIME (seconds)
M116A3 YAW ANGLE (radians) vs TIME (seconds)

16


12-inch Pothole at 10 mph
0.15
0.10
0.05
0.00
-0.05
0
2
4
6
8
10
M116A2E2 YAW ANGLE (radians) vs TIME (seconds)
M116A3 YAW ANGLE (radians) vs TIME (seconds)

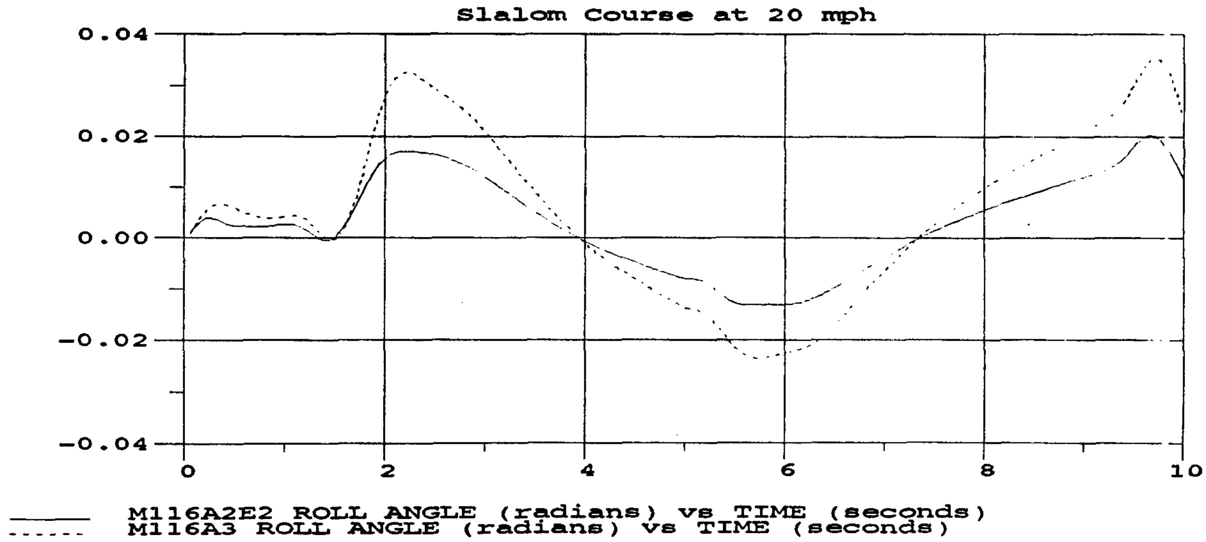
17


12-inch Pothole at 15 mph
0.15
0.10
0.05
0.00
-0.05
0
2
4
6
8
10
M116A2E2 YAW ANGLE (radians) vs TIME (seconds)
M116A3 YAW ANGLE (radians) vs TIME (seconds)

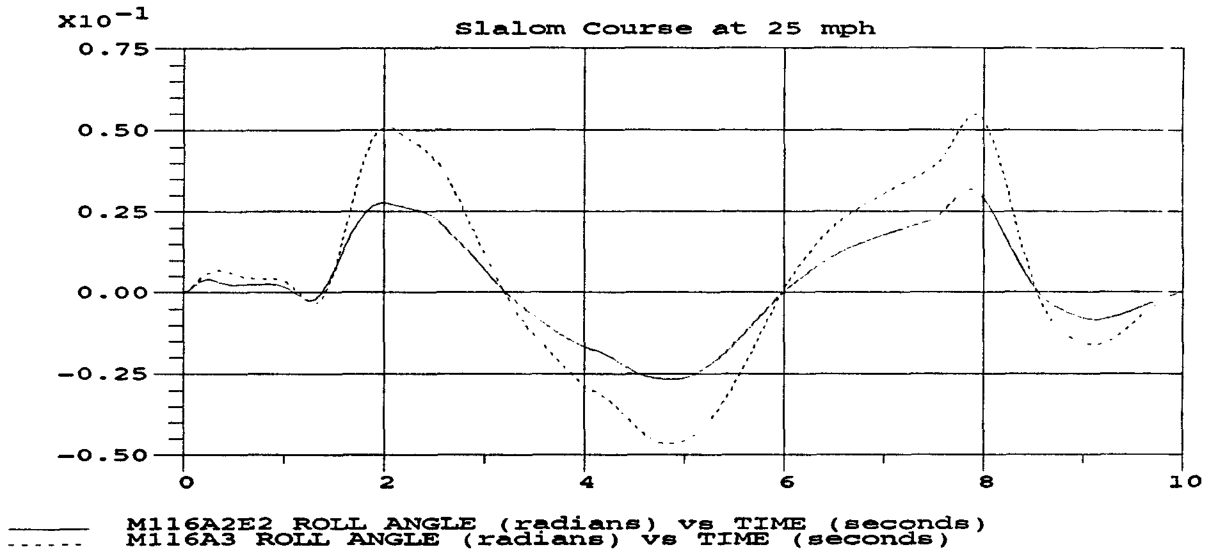
18

APPENDIX C

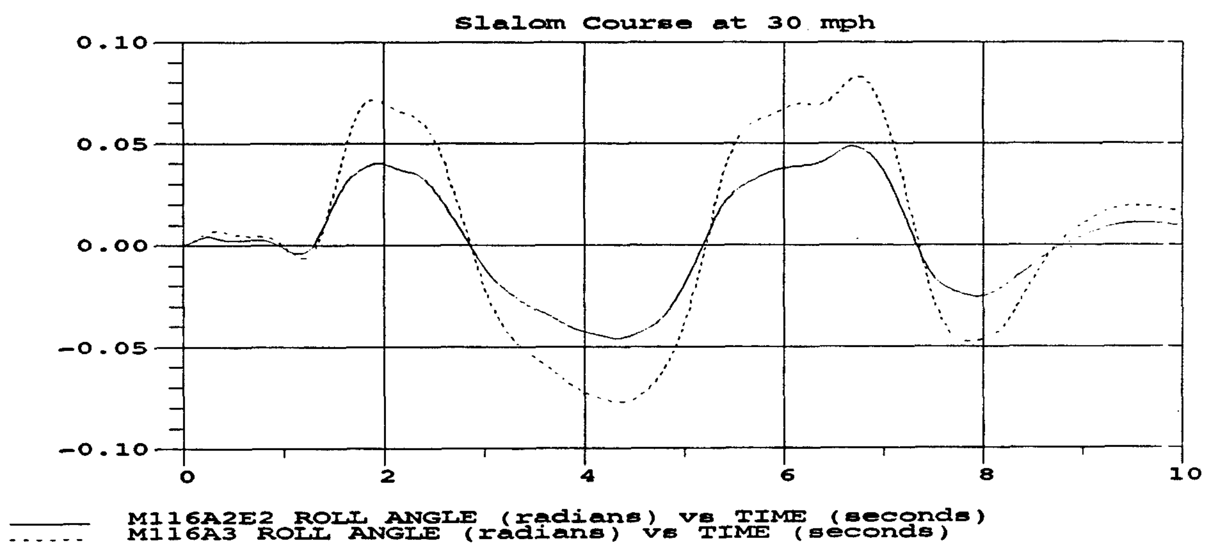
Time History Plots of Slalom Course Simulations


Slalom Course at 20 mph
0.04
0.02
0.00
-0.02
-0.04
0
2
4
6
8
10
M116A2E2 ROLL ANGLE (radians) vs TIME (seconds)
M116A3 ROLL ANGLE (radians) vs TIME (seconds)

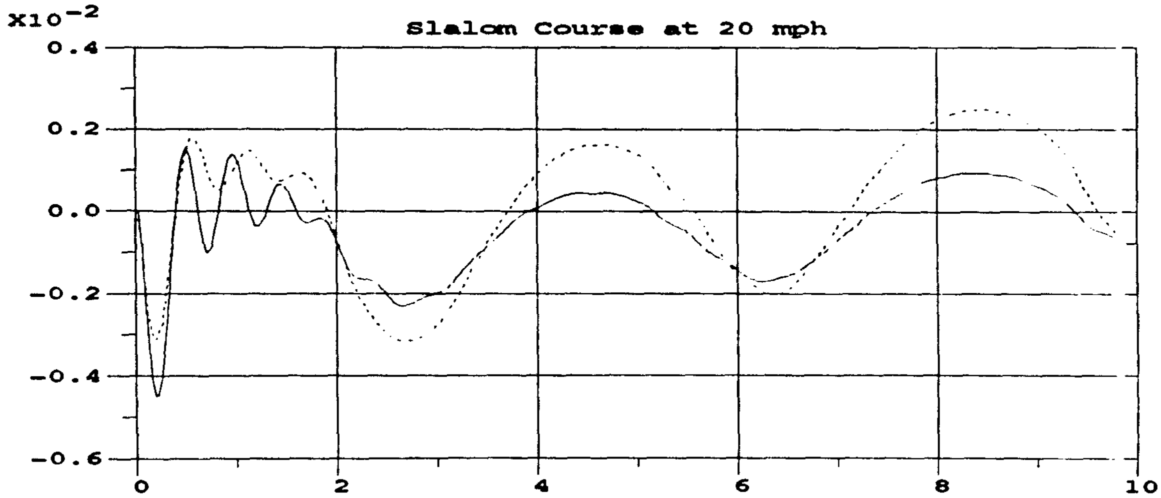
1


X10^-1
Slalom Course at 25 mph
0.75
0.50
0.25
0.00
-0.25
-0.50
0
2
4
6
8
10
M116A2E2 ROLL ANGLE (radians) vs TIME (seconds)
M116A3 ROLL ANGLE (radians) vs TIME (seconds)

2

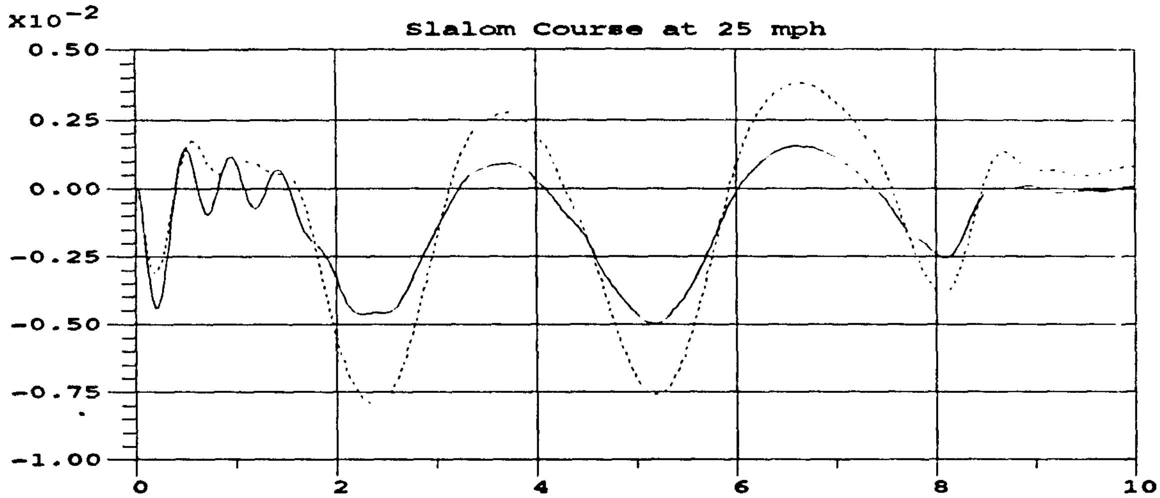

Slalom Course at 30 mph
0.10
0.05
0.00
-0.05
-0.10
0
2
4
6
8
10
M116A2E2 ROLL ANGLE (radians) vs TIME (seconds)
M116A3 ROLL ANGLE (radians) vs TIME (seconds)

3



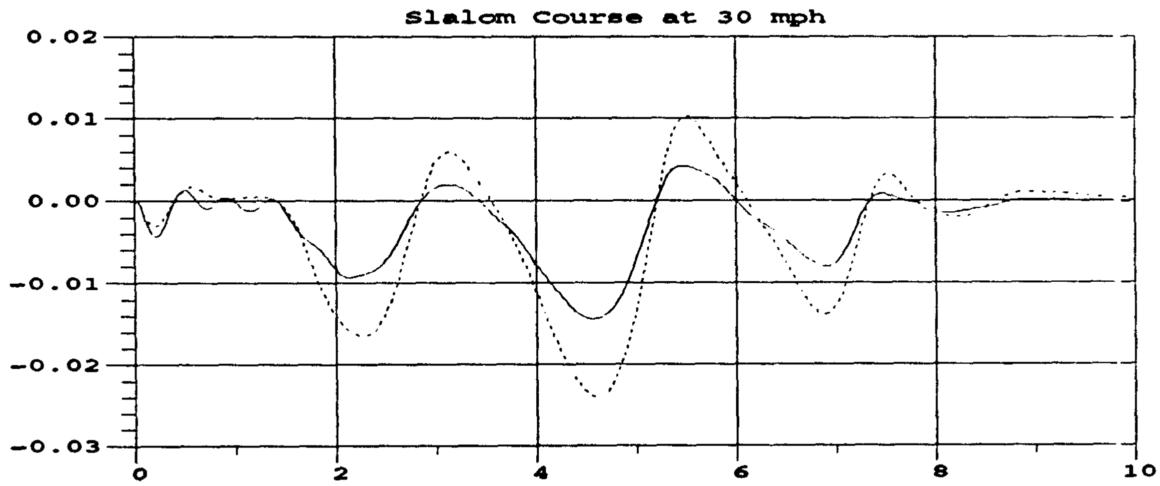
M116A2E2 PITCH ANGLE (radians) vs TIME (seconds)
M116A3 PITCH ANGLE (radians) vs TIME (seconds)

4



M116A2E2 PITCH ANGLE (radians) vs TIME (seconds)
M116A3 PITCH ANGLE (radians) vs TIME (seconds)

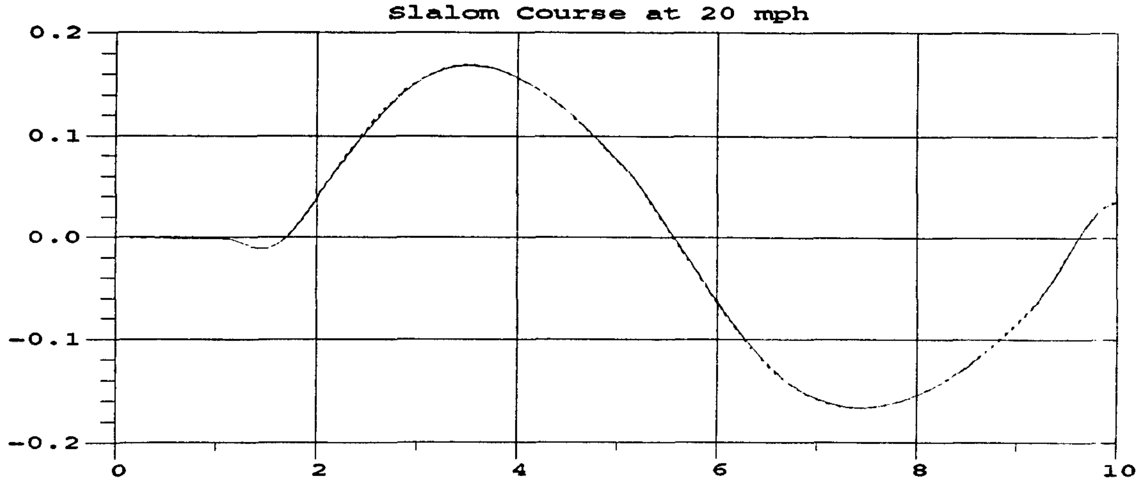
5



M116A2E2 PITCH ANGLE (radians) vs TIME (seconds)
M116A3 PITCH ANGLE (radians) vs TIME (seconds)

6

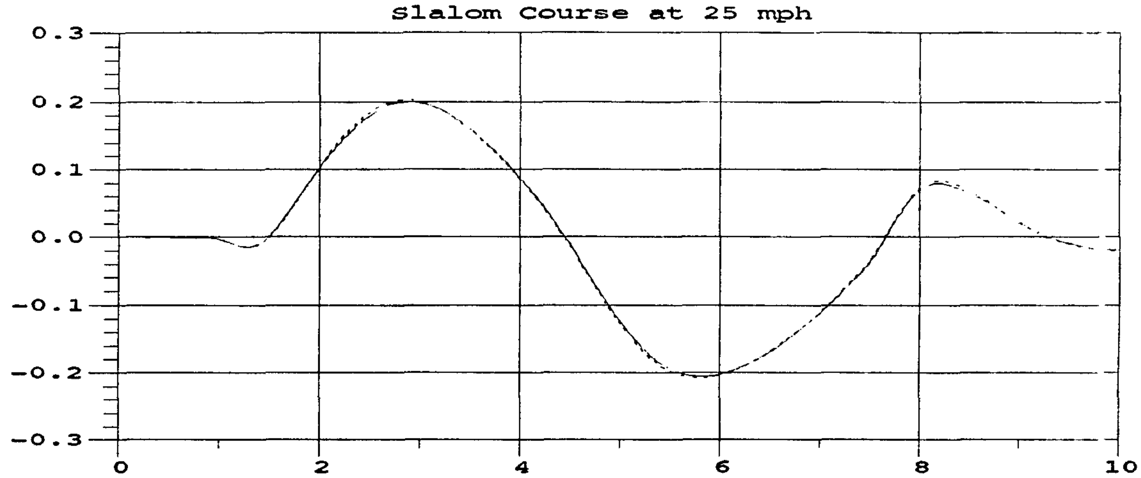
Slalom Course at 20 mph



M116A2E2 YAW ANGLE (radians) vs TIME (seconds)
M116A3 YAW ANGLE (radians) vs TIME (seconds)

7

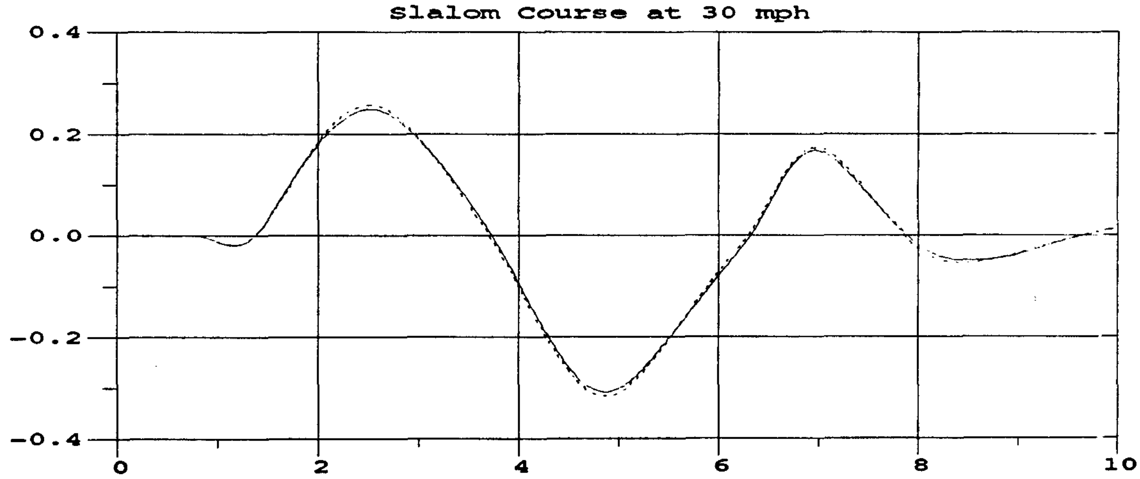
Slalom Course at 25 mph



M116A2E2 YAW ANGLE (radians) vs TIME (seconds)
M116A3 YAW ANGLE (radians) vs TIME (seconds)

8

Slalom Course at 30 mph

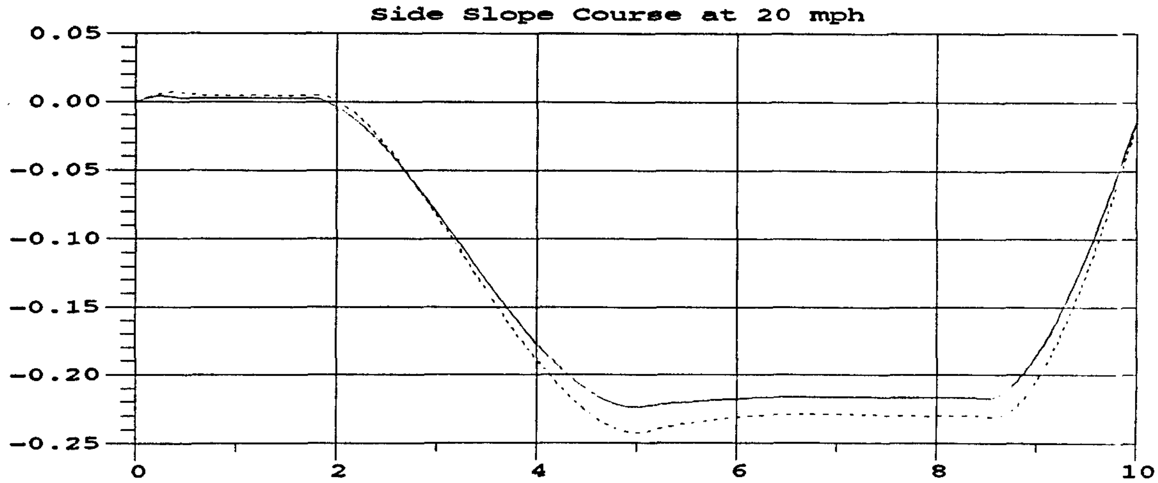


M116A2E2 YAW ANGLE (radians) vs TIME (seconds)
M116A3 YAW ANGLE (radians) vs TIME (seconds)

9

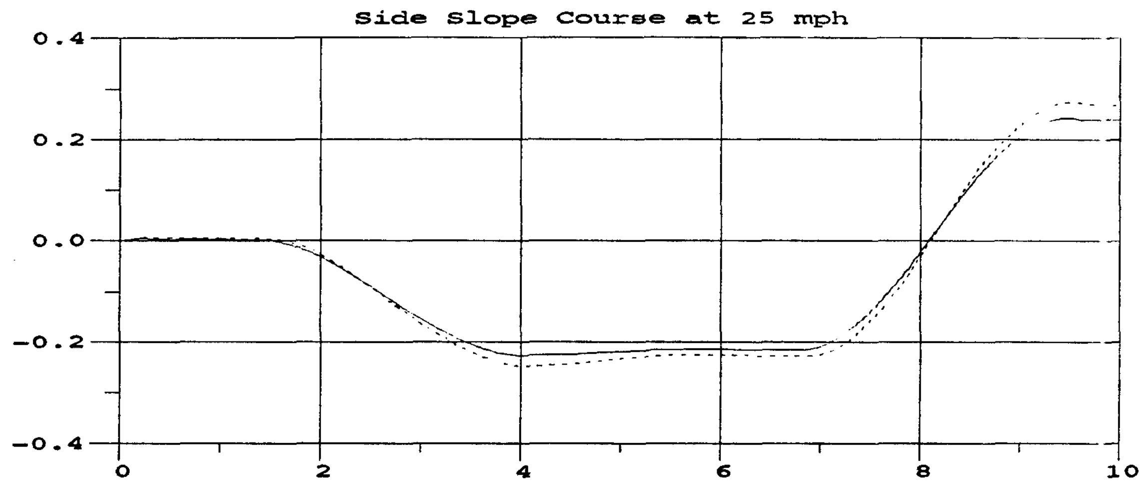
APPENDIX D

Time History Plots of Side Slope Course Simulations



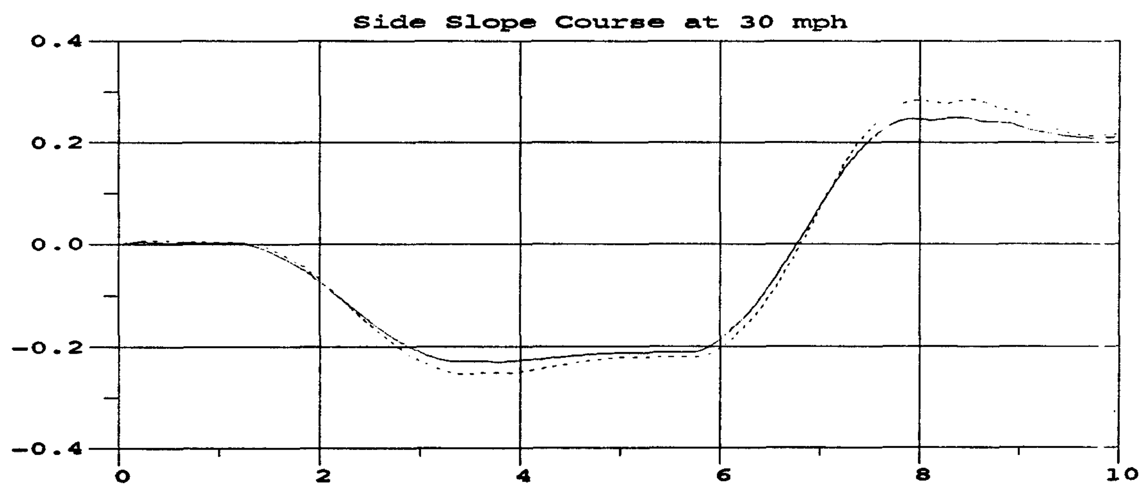
M116A2E2 ROLL ANGLE (radians) vs TIME (seconds)
M116A3 ROLL ANGLE (radians) vs TIME (seconds)

1



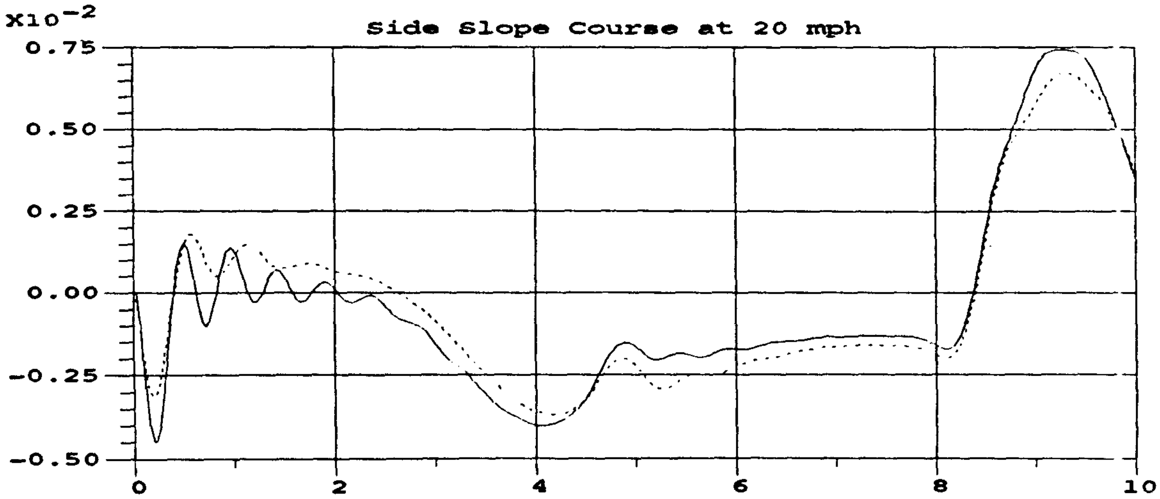
M116A2E2 ROLL ANGLE (radians) vs TIME (seconds)
M116A3 ROLL ANGLE (radians) vs TIME (seconds)

2



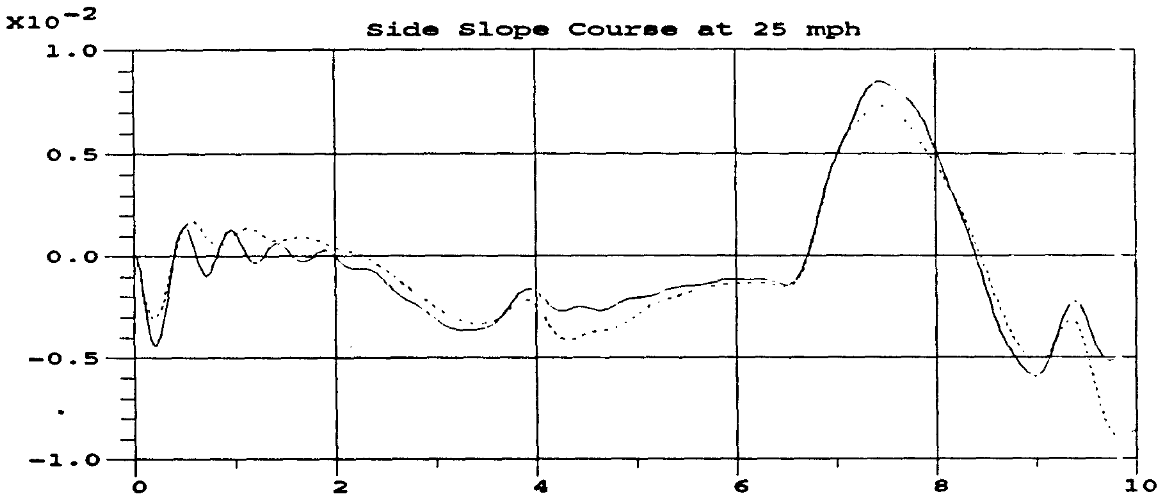
M116A2E2 ROLL ANGLE (radians) vs TIME (seconds)
M116A3 ROLL ANGLE (radians) vs TIME (seconds)

3



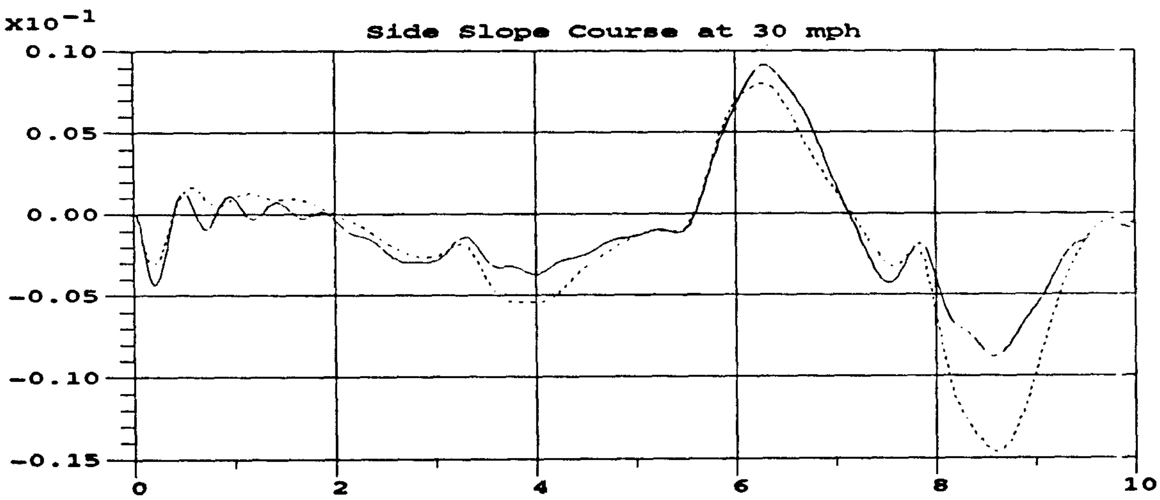
———— M116A2E2 PITCH ANGLE (radians) vs TIME (seconds)
...... M116A3 PITCH ANGLE (radians) vs TIME (seconds)

4



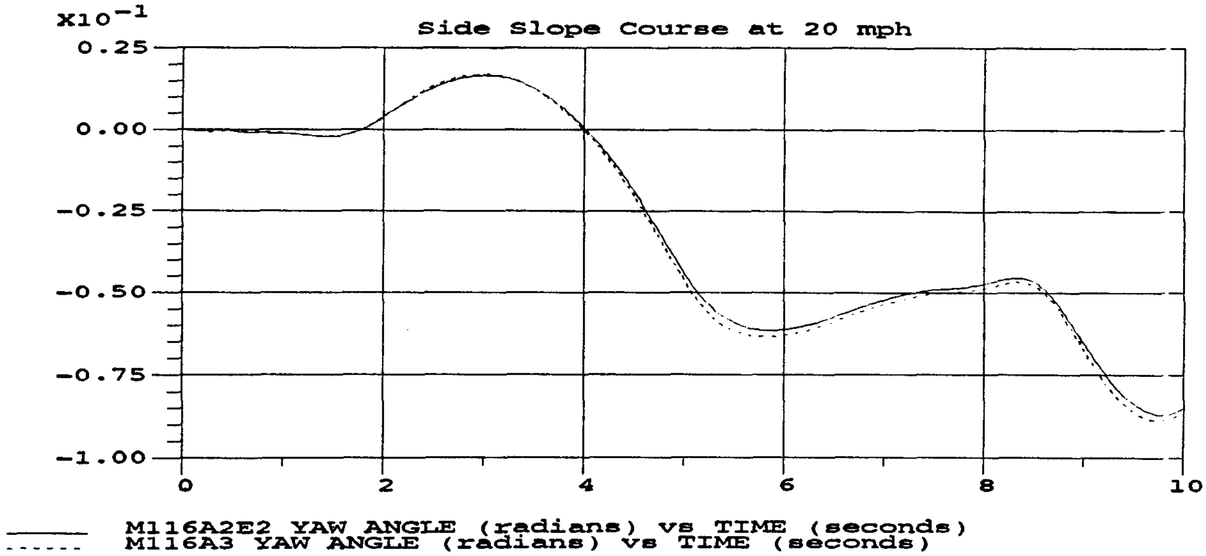
———— M116A2E2 PITCH ANGLE (radians) vs TIME (seconds)
...... M116A3 PITCH ANGLE (radians) vs TIME (seconds)

5

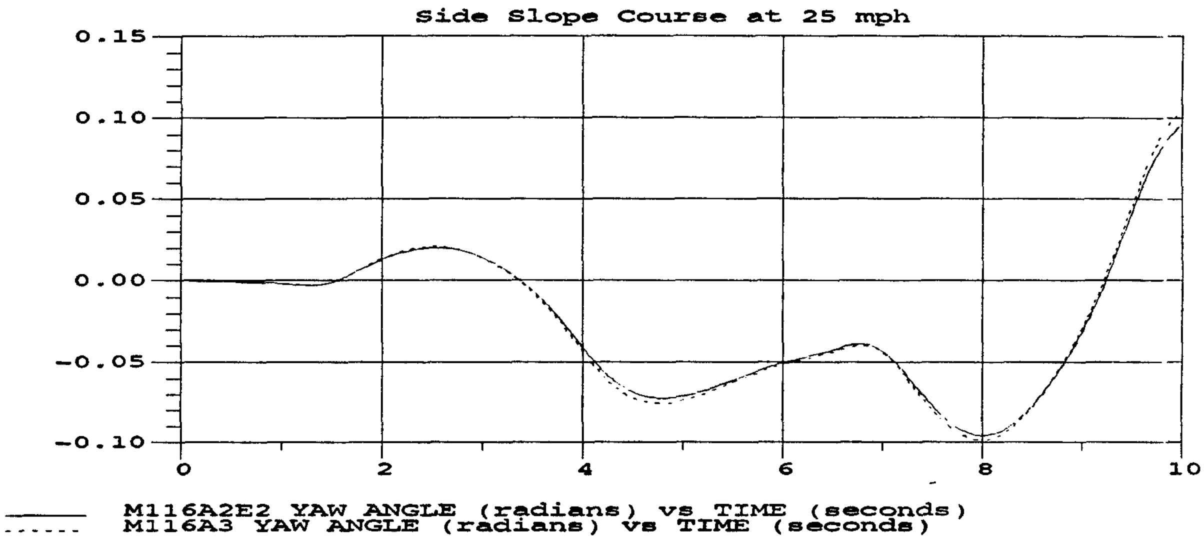


———— M116A2E2 PITCH ANGLE (radians) vs TIME (seconds)
...... M116A3 PITCH ANGLE (radians) vs TIME (seconds)

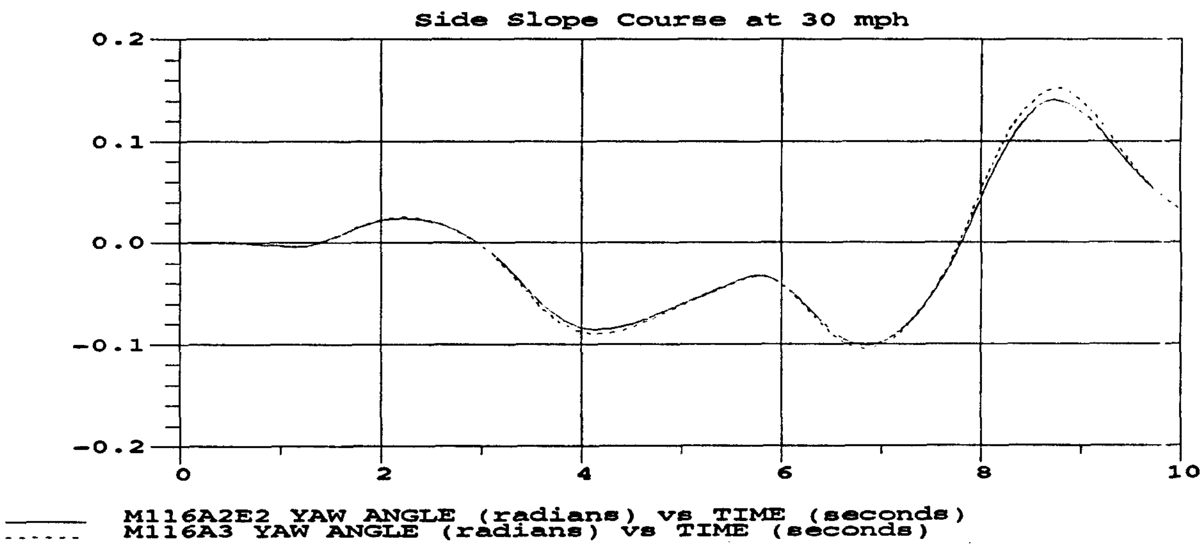
6


x10^-1
Side Slope Course at 20 mph
0.25
0.00
-0.25
-0.50
-0.75
-1.00
0
2
4
6
8
10
M116A2E2 YAW ANGLE (radians) vs TIME (seconds)
M116A3 YAW ANGLE (radians) vs TIME (seconds)

7


Side Slope Course at 25 mph
0.15
0.10
0.05
0.00
-0.05
-0.10
0
2
4
6
8
10
M116A2E2 YAW ANGLE (radians) vs TIME (seconds)
M116A3 YAW ANGLE (radians) vs TIME (seconds)

8

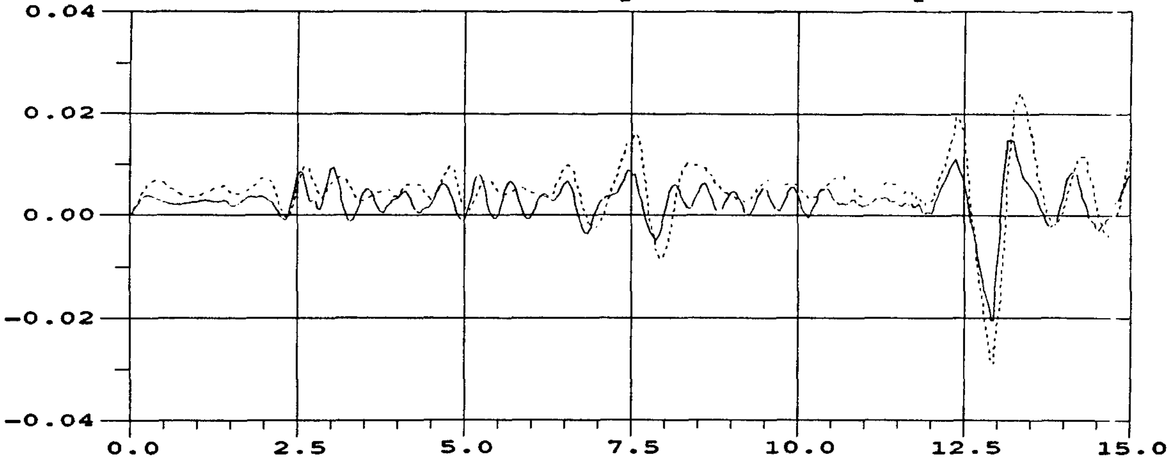

Side Slope Course at 30 mph
0.2
0.1
0.0
-0.1
-0.2
0
2
4
6
8
10
M116A2E2 YAW ANGLE (radians) vs TIME (seconds)
M116A3 YAW ANGLE (radians) vs TIME (seconds)

9

APPENDIX E

Time History Plots of APG 11 Cross-Country Course Simulations

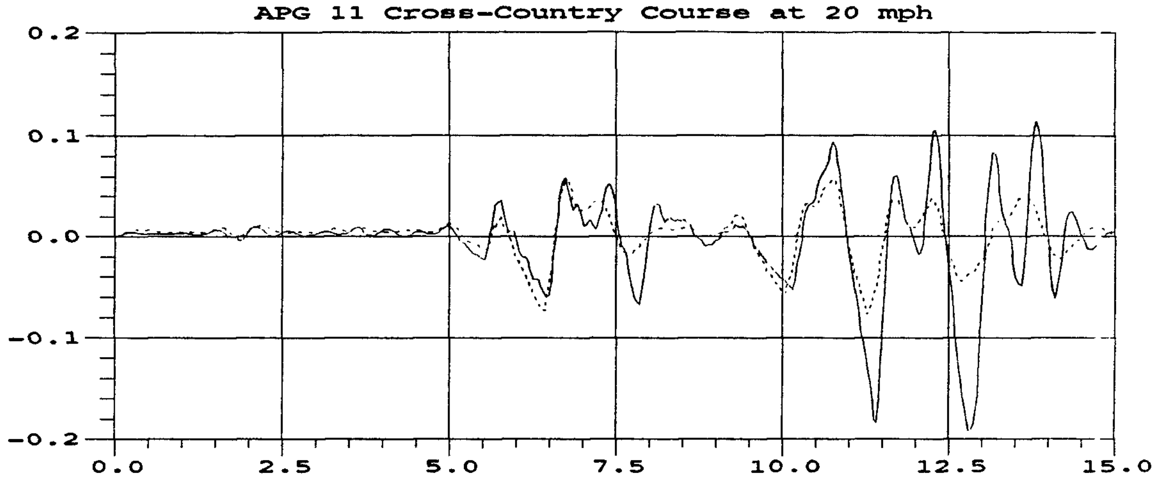
APG 11 Cross-Country Course at 15 mph



M116A2E2 ROLL ANGLE (radians) vs TIME (seconds)
M116A3 ROLL ANGLE (radians) vs TIME (seconds)

1

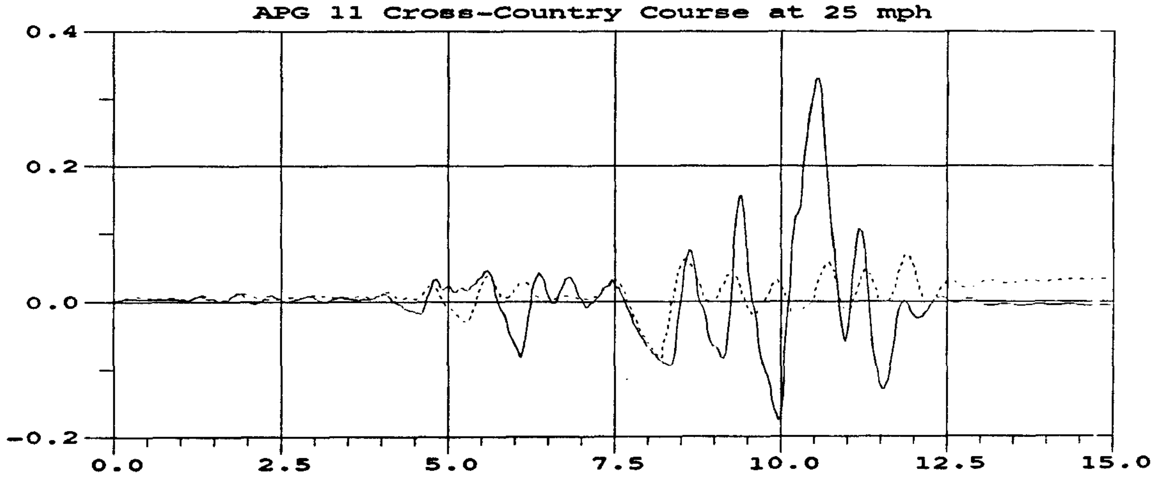
APG 11 Cross-Country Course at 20 mph



M116A2E2 ROLL ANGLE (radians) vs TIME (seconds)
M116A3 ROLL ANGLE (radians) vs TIME (seconds)

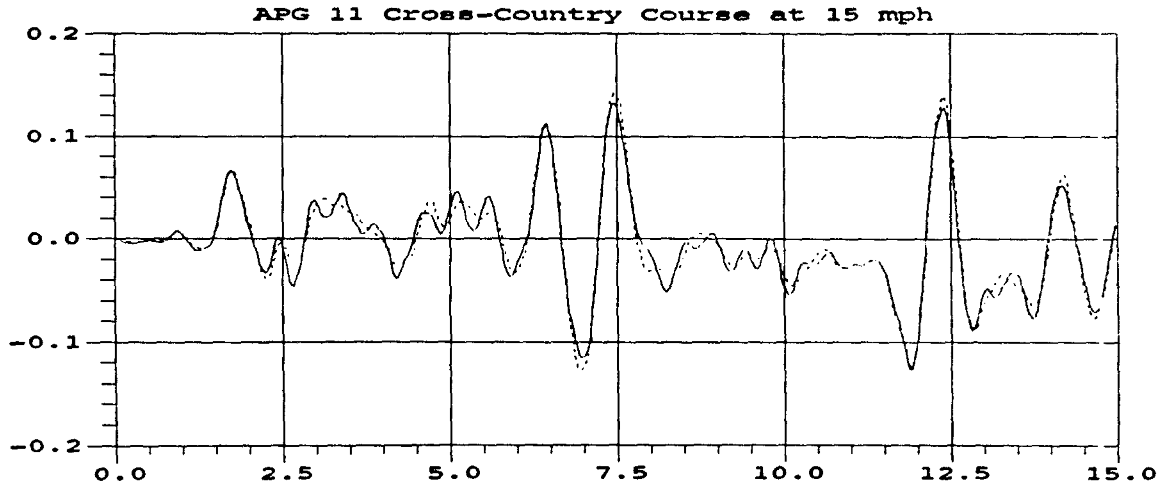
2

APG 11 Cross-Country Course at 25 mph



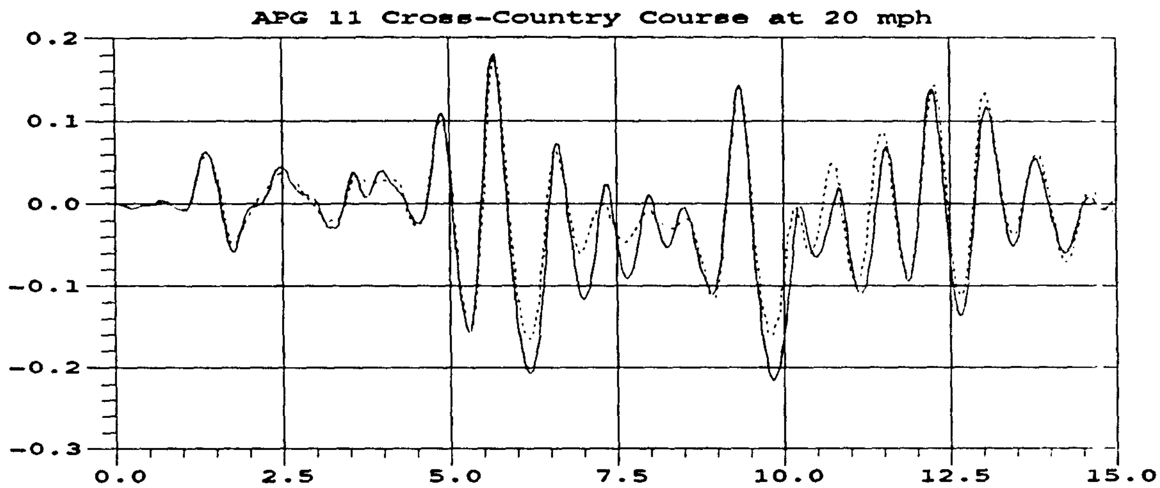
M116A2E2 ROLL ANGLE (radians) vs TIME (seconds)
M116A3 ROLL ANGLE (radians) vs TIME (seconds)

3



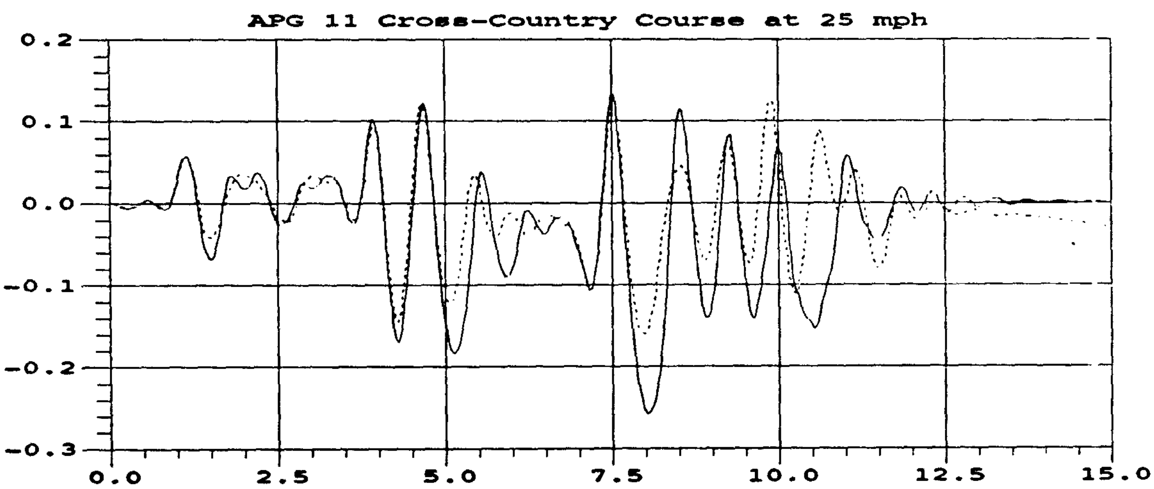
M116A2E2 PITCH ANGLE (radians) vs TIME (seconds)
M116A3 PITCH ANGLE (radians) vs TIME (seconds)

4



M116A2E2 PITCH ANGLE (radians) vs TIME (seconds)
M116A3 PITCH ANGLE (radians) vs TIME (seconds)

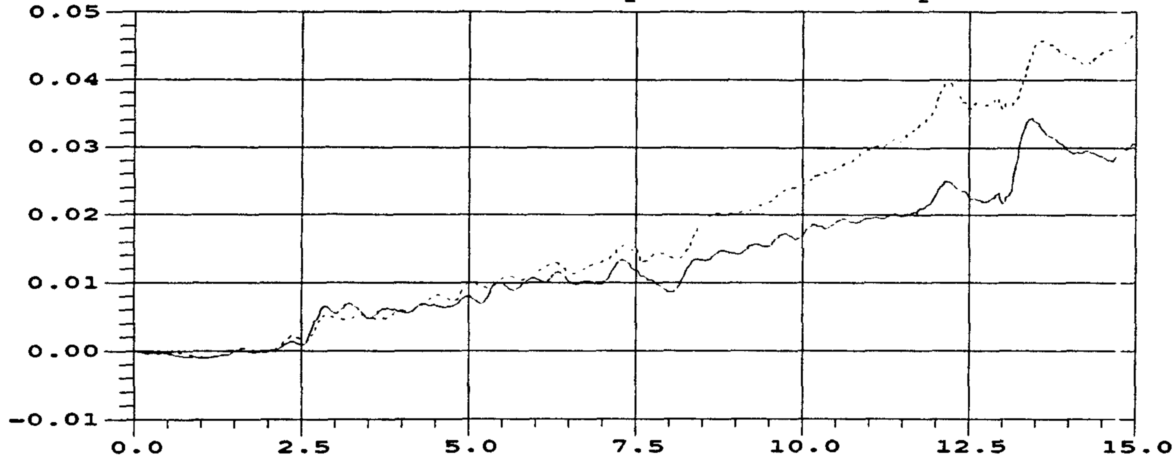
5



M116A2E2 PITCH ANGLE (radians) vs TIME (seconds)
M116A3 PITCH ANGLE (radians) vs TIME (seconds)

6

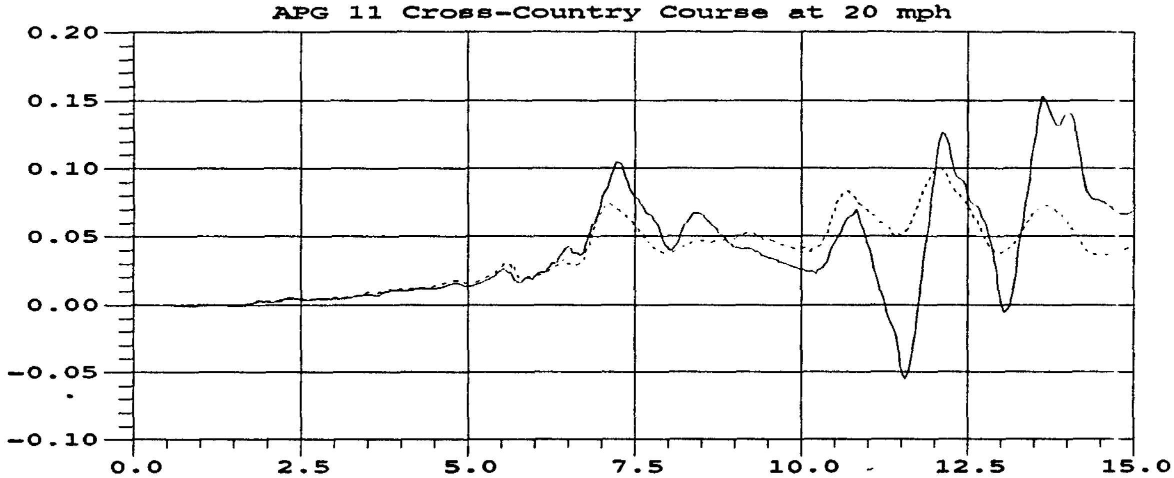
APG 11 Cross-Country Course at 15 mph



M116A2E2 YAW ANGLE (radians) vs TIME (seconds)
M116A3 YAW ANGLE (radians) vs TIME (seconds)

7

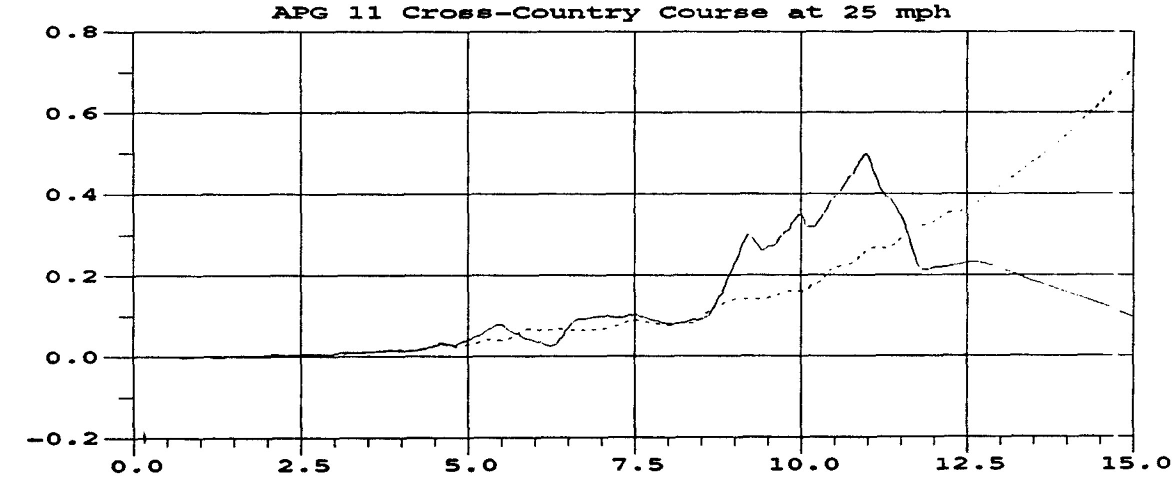
APG 11 Cross-Country Course at 20 mph



M116A2E2 YAW ANGLE (radians) vs TIME (seconds)
M116A3 YAW ANGLE (radians) vs TIME (seconds)

8

APG 11 Cross-Country Course at 25 mph



M116A2E2 YAW ANGLE (radians) vs TIME (seconds)
M116A3 YAW ANGLE (radians) vs TIME (seconds)

9

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